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Introduction to SASE: Standards Analysis, Synthesis, and Expression

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May 1987

U.S. DEPARTMENT OF COMMERCE
EAU OF STANDARDS

NBSIR 87-3513

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U.S. DEPARTMENT OF COMMERCE, Malcolm Baldrige, ***Secretary***
NATIONAL BUREAU OF STANDARDS, Ernest Ambler, ***Director***

ABSTRACT

The Standards Analysis, Synthesis, and Expression (SASE) methodology provides an objective and rigorous representation of the content and organization of a standard. Both the methodology and a computer program that implements it are described in this document in terms of two underlying conceptual models. The conceptual model for the information content of a standard is essentially independent of any particular organization and expression of the information. The fundamental unit of information in the model is a provision stipulating that a product or process have some quality. The highest level provisions in a standard are requirements that directly indicate compliance with some portion of the standard and are either satisfied or violated. Techniques are provided in SASE to ensure that individual provisions are unique, complete, and correct, and that the relations between provisions are connected, acyclic, and consistent. Entities in SASE that represent the information content of a standard are data items, decision tables, decision trees, functions, and information networks. The conceptual model for the organization of a standard is based on a logical classification system in which each requirement is classed in terms of its subject (product or process) and predicate (required quality). Techniques are provided in SASE for building and manipulating hierarchical trees of classifiers and testing the resulting organization for completeness and clarity. Entities in SASE that deal with the organization of a standard are classifiers, hierarchy, scopelist, index, organization, and outline. The SASE methodology is demonstrated in an analysis of a complete standard for concrete quality. An annotated bibliography of the most significant relevant research reports is presented.

keywords: Arrangement, building, classification, code, consistency, knowledge representation, organization, provisions, standards

FOREWORD

This report is intended to serve two purposes:

- To provide an introduction to the methodology of Standards Analysis, Synthesis, and Expression (SASE) by summarizing in one place the concepts and methods developed over nearly two decades; and

- To serve as a tutorial guide to the SASE program which implements that methodology.

A chronological annotated bibliography of the publications leading up to this report is presented in Appendix B. The documentation of the SASE program is contained in the companion SASE User Manual*.

The writers appreciate the contributions of several colleagues. Judy Calabrese and Charles Yancey assisted with the study described in Appendix A. James Harris made a considerable contribution to the design of the SASE software and the planning of this study, and was lead author of the principal resource document. Steven Bushby provided numerous insightful comments in his critical review of the manuscript. Systems Architects, Inc. of Falls Church, Virginia, prepared the initial version of the SASE program.

* NBSIR 87-3514. See reference 4 of this report.

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1. INTRODUCTION

The Standards Analysis, Synthesis, and Expression (SASE) methodology provides an objective and rigorous representation of the meaning of a standard. It is intended to assist organizations engaged in the formulation, promulgation, and maintenance of standards. In order to put SASE in context, this chapter presents first a discussion of standards followed by a discussion of the role of SASE. Finally, the organization of this document is discussed.

1.1 Standards

In this discussion, the term standard includes all types of normative documents used to define the required qualities of buildings, building products, materials, or building processes. The term includes legal building regulations, consensus standards such as those of the American National Standards Institute and of the International Organization for Standardization, and proprietary specifications. Standards are used for communication between buyer and seller and for protection of public health, safety, and welfare.

Standards from many technology areas should be equally amenable to the SASE methodology. However, the methodology and the information models on which it is based have been tested extensively only in areas of building technology.

1.1.1 The Standards Development Process

Standards are generally developed following the principle of due process in notification, balloting, resolution of dissent, and careful record keeping. A standard is usually drafted by a committee of experts who:

- define the scope, including the products or processes to be covered and their required performance attributes;

- determine whether to express the standard as a performance standard (attributes in terms of user needs [19]), procedural standard (attributes in terms of specified, rigorous technical evaluation procedures [5]), or prescriptive standard (attributes given as dimensions or properties completely defining the acceptable configuration or procedures);

- formulate the standard, that is, develop appropriate provisions for ascertaining that the required performance attributes of the products or processes are satisfied; and

- submit the draft standard to the organization responsible for promulgation and maintenance.

The process of promulgation and maintenance is typically of long duration. Modifications and interpretations may occur without participation of or consultation with the experts who initially drafted the standard.

1.1.2 Shortcomings of the Process

A number of problems arise in the present process of developing standards. First, the process itself is expensive because much time and effort is required from leading experts in the subject area and from those whose interests are affected. Most of this time and effort is expended in mutually understanding technical issues and resolving them.

Second, the slowness of the process means that standards may become obsolete or even technically incorrect and continue to be used for some time while new or modified standards are being developed. This problem is exacerbated by rapidly changing societal demands for building qualities, such as energy conservation, and rapidly changing technologies in building products and processes, both of which lead to many new subjects for standardization and the frequent revision of existing standards.

Third, once a standard is developed, each user of the standard must invest time and effort in interpreting it, that is:

- locating all relevant provisions; and
- understanding and correctly applying the applicable provisions.

Ultimately, society bears the additional risks and expenses that arise from the potential building malfunctions and waste associated with the use of obsolete, incorrect, or incorrectly applied standards.

The increased use of computer-aided design potentially magnifies these problems. A single error in interpretation of a standard by the developer of a computer program may lead to many errors in application as the program is used. Furthermore, the time and expense associated with updating programs to incorporate revisions in standards cause programs to lag behind and to act as impediments to the application of improved technologies that can increase the economy, safety, or usefulness of buildings.

An objective, analytical method for generating and reviewing either the content or the form of a proposed new standard or modifications of an existing one would help mitigate the problems described above by providing experts and users both with explicit representations of the content and organization of the standard. Because standards are so important to industry and because the cost of producing them is high, there is a need for such a method, beyond due process, informal peer review, and occasional test comparisons with previous standards, for making objective evaluations of the logic and internal consistency of standards. The SASE methodology fills this need.

1.2 Role of SASE in the Standards Development Process

The methodology embodied in SASE deals exclusively with the logic, format, and organization of standards, that is, their syntax. Because of this emphasis on syntax, SASE is applicable to the entire range of standards

discussed in section 1.1. By contrast, the meaning or semantics of each standard is highly specific to its subject area, and requires the background and knowledge of experts in the area for proper analysis and synthesis.

The objective of SASE is to provide a formal methodology to represent the logic and organization of standards so as to ensure the following qualities in a standard:

1. Individual provisions need to be:

   - Unique - the provision must yield one and only result in any possible application;

   - Complete - the provision must apply explicitly to all possible situations; and

   - Correct - the result of applying the provision is to be consistent with the objective of the standard.

2. Relations among provisions should be:

   - Connected - explicit cross references must show the data required for the application of each provision and the use stipulated for the data produced by each provision.

   - Acyclic - the data produced by evaluation of a provision should not be required prior to its evaluation (no loops in logic); and

   - Consistent - uniform logical and technical bases must be provided for comparable provisions.

3. The organization of the standard should be:

   - Complete - explicit scope must be provided so that a user knows the subjects and qualities covered by the standard; and

   - Clear - the arrangement and display of provisions should be such that the user readily finds all provisions pertinent to his query.

1.2.1 The Application of SASE

The methodology of SASE is applicable to three distinct processes in standards development.

1. Analysis - the process of extracting the information content of an existing standard. This is the necessary first step in modifying or updating an existing standard.

2. Synthesis - the process of generating the information content of a new or modified standard. This process is most directly concerned with ensuring that the standard possesses the qualities presented previously.

3. Expression - the process of expressing the previously synthesized information content in textual form.

The first two processes are collectively referred to as the formulation of a standard since they lead to the format and complete representation of the information content.

1.2.2 Mode of usage of SASE

SASE may be used in the development of a standard by designating one or more members of the standards drafting committee as analysts, whose primary responsibility is to work with SASE on issues of format and organization, interacting closely with the other committee members who are experts in the area covered by the standard. Alternatively, organizations involved in standards activities may provide analytical services to their committees as a staff support function. In either event, analysis should be closely coordinated with the standards formulation process.

For a project that involves the formulation of a new standard, systematic analysis using SASE should begin at the same time as the overall project of standards drafting and be closely coordinated with it. This avoids the possibility of the analyst appearing as an intruder, and allows the analyst to keep up with the experts.

For a project that involves a revision of an existing standard, it is desirable to begin analysis of the standard before the committee begins considering revisions. Once again, this allows the analyst to keep up with the committee. It also allows a thorough study of the possible flaws in the existing provisions, which could serve as part of the rationale for change.

Once the analysis has been undertaken, it should be kept up to date as the project continues. There are several advantages accruing from concommitant analysis:

- it provides a firm, rational basis for recommendations to be made to the experts;

- the details of the analysis may be important to some of the experts in their deliberations; and

- the final SASE documentation can be completed and released with the written standard or very soon after its completion.

Effective interaction between the analysts and the experts is of the utmost importance. Close and frequent contacts facilitate the work and greatly improve the likelihood of significant benefit. Analysis, synthesis, and

expression of any standard are too important to the success of the standard-writing project to be delegated to a format committee remote from the main thrust of the work. The analysts should interact directly with the committee concerned with the substance of the standard, for that is where the key issues will arise and the decisions will be made. It can become easy to fall into adversative positions when the experts and the analysts are too far removed from one another because of the organizational structure. Close contact increases the spirit of cooperation and lessens the chance of the analyst antagonizing the experts. Successful interaction also requires quick response.

Typically, recommendations generated by the analysts come in the form of a question raised or of an improvement suggested. Both forms are valid but, with every recommendation, it must be clear what the form is and what the appropriate action for the experts is. In addition, all recommendations must be carefully explained, with due consideration of present problems and the impacts of change. Finally, the participants in such projects must frequently conduct critiques of their work, their own effectiveness in the work, and the standard that they are working on.

In summary, the following items are critical components for the successful use of SASE in a standards development project:

- begin analysis at the earliest possible time;
- obtain early agreement within the committee on the interaction between experts and analysts;
- conduct a full, detailed analysis early and keep the analysis up to date;
- cultivate close and effective interactions between experts and analysts;
- make all recommendations clear; and
- conduct on-going critiques.

1.3 Organization of this Document

This document is directed primarily to analysts participating in standard development activities. The document is intended to provide the background on the SASE methodology and tutorial guidance on the SASE program. It is expected that the document will be used in conjunction with the SASE User Manual [4], both to provide the motivation for and an understanding of the features in SASE and to serve as an illustrative guide for the use of these features.

Portions of this document, especially Chapter 2 but also the introductory material and examples of Chapter 3 and Chapter 4, should be of interest not just to analysts but to all experts participating in standard developing

committees. This material will provide an understanding of the types of assistance that can be provided to the experts by analysts using SASE.

A brief overview of the conceptual model incorporated in the SASE methodology and of the representation of the principal components of a standard in the SASE program is presented in Chapter 2.

Detailed descriptions of the process of modelling and organizing the information of a standard according to the conceptual model are provided in Chapter 3 and Chapter 4. Each of the major sections of these chapters is subdivided into three parts:

- a detailed definition of the concept presented in the section, including background information;

- a discussion of proper usage of the concept, containing suggestions to serve as tutorial aids; and

- the representation of the concept in the SASE program.

The results of a study of a standard for concrete quality are presented in Appendix A as a practical demonstration of the SASE methodology. Virtually all of the SASE techniques described in this report were applied in the study.

2. OVERVIEW OF SASE

This chapter presents a brief overview of the conceptual model incorporated in the SASE methodology and of the representation of the principal components of a standard in the SASE program.

2.1 The SASE Methodology

This overview of the SASE methodology is illustrated by a completed analysis of a section of a model building code [1] dealing with fire escapes. The text of the fire escape example is shown in figure 2.1. The underlined portions of the text correspond to data items identified in the analysis; the numbers in the right margin of the figure are datum reference numbers assigned by the analyst.

2.1.1 Provisions

The basic unit of a standard is a provision or normative statement stipulating that a product or process shall have or be assigned some quality. A number of forms of provisions fit this definition:

- a performance requirement, e.g., "the system shall maintain an adequate supply of hot water,"

- a performance criterion, e.g., "hot water temperature shall be controlled between 40°C and 50°C,"

- a prescriptive criterion, e.g., "the hot water tank shall have a capacity of 150 liters,"

- a determination or function, e.g., "the flow q = av."

Each provision has the function of assigning a value to a data item or datum. It is useful to distinguish between two kinds of provisions based on their usage in the standard:

- Requirements are provisions that directly determine compliance with some portion of a standard. Such provisions normally can be characterized as satisfied or violated, represented by the Boolean data values true or false, respectively.

- Determinations are all provisions that are not requirements. Such provisions are normally characterized by either numerical or nominal values, including Boolean, but are not amenable to characterization as satisfied or violated.

Seven requirements were identified in the analysis of the fire escape example. They are described in terms of their corresponding data items in the following section.

Section 623.0 Fire Escapes

623.1 Where Permitted: Except in use groups L-2 and L-3 (one- 2
and two-family and multi-family dwellings), fire escapes shall
not in general be accepted as an element of a required means of
egress. Fire escapes shall be permitted only by special order 1,3
of the building official, in existing buildings or structures 4
of other use groups, not exceeding five (5) stories or sixty- 6
five (65) feet in height, when constructed in accordance with 7
the approved rules and when more adequate exitway facilities 9
cannot be provided.

623.2 Location: When located on the front of the building and 10
projecting beyond the building line, the lowest landing shall 11,12
be not less than ten (10) or more than fourteen (14) feet above
grade, equipped with a counterbalanced stairway to the street 13
and with fixed ladder to the roof. In alleyways and thorough- 14,15
fares less than thirty (30) feet wide, the clearance under the 29
lowest landing shall not be less than fourteen (14) feet.

623.3 Construction: The fire escape shall be designed to sup- 8
port a live load of one hundred (100) pounds per square feet 16
and shall be constructed of steel or other approved noncombus- 17,30
tible materials.

623.31 Dimensions: Stairs shall be at least twenty-two (22) 31
inches wide with risers not more and treads not less than eight 21-23
(8) inches and landings at foot of stairs not less than forty 35
(40) inches wide by thirty-six (36) inches long, located not 24-26
more than eight (8) inches below the access window or door.

623.32 Opening Protectives: Doors and windows along the fire 34
escape shall be protected with three-quarter (3/4) hour opening 27
protectives in other than residence buildings of use groups L-2
and L-3.

623.33 Outside Fire Limits: On buildings not over three (3)
stories nor more than forty (40) feet in height located outside
the fire limits, accomodating not more than twenty (20) per- 32
sons, fire escapes may be constructed of wood or other approved 33
material of similar combustible characteristics.

623.34 Within Fire Limits: Within Fire District No. 2, fire 20,28
escapes may be constructed of wood not less than two (2) inches 18
thick on buildings of type 3 or type 4 construction not more 19
than three (3) stories in height.

Figure 2.1 Text of fire escape example with data items underlined and datum reference numbers in right margin.

2.1.2 Data Items

A data item or datum is a precise identification of an information element occurring in a standard. The status (satisfied or violated) of each requirement is represented by a datum. Each result or variable generated by a determination is a datum. In addition, every other variable referred to in a standard but not explicitly assigned a value by some provision is a datum. For example, the density of a material may be referred to, but not defined, in a standard. Such data are called input data; their values are not determined by the standard itself. All data assigned values by provisions of the standard are called derived data. The list of data items is similar to, but typically much longer than, the conventional list of definitions and symbols found in present standards.

The set of data items plus the expressions of the rules for evaluating and relating the data items contain all the information necessary to evaluate compliance with a standard.

The data items for the fire escape example are listed by reference number in table 2.1. The reference numbers were assigned as the analyst identified each datum and are not necessarily in the order of appearance in the text. Each datum is described by a short title. It is instructive to compare the titles in table 2.1 with the underlined portions of text in figure 2.1. Frequently, a verbatim extraction of text does not suffice to capture the meaning of an information element and the title must be synthesized.

Each datum in table 2.1 is also described by the source of its value (e.g., input or derived); and, if derived, the reference numbers of the ingredient data items on which its value depends (see section 2.1.4). Note that datum 5 in the table is neither a derived datum nor an ingredient of any datum. It was entered by the analyst expecting to encounter a height limit within this section and was retained because it may be an ingredient to a datum in another section of the standard.

2.1.3 Decision Tables

A decision table is used to represent the rules for assigning a value to a derived datum. A decision table is an orderly presentation of the reasoning leading to a decision. It is easily analyzed to assure that the reasoning leads to a unique result in each case and that no possibility exists for encountering an unanticipated situation.

The seven decision tables given in tables 2.2 through 2.8 correspond to the seven requirements identified in the fire escape example.

Each decision table is divided into four quadrants (in this representation, by the double lines). The upper left quadrant is the condition stub defining all logical conditions that have a bearing on the actions. The lower left quadrant is the action stub defining all possible actions. The upper right quadrant is the condition entry and the lower right quadrant is the action entry. The rules defining the logic of the decision table are the columns spanning the entry quadrants. The horizontal rows of conditions

Table 2.1 Datum list for fire escape example

Reference Number	Title	Source	Ingredient Data Items
1	Requirement for permission to use fire escapes	Derived	2,3,4,6,7,9
2	Use group	Input	
3	Special order of building official	Input	
4	Existing building	Input	
5	Height limit	Input	
6	Number of stories	Input	
7	Height of building	Input	
8	Requirement for design load of fire escapes	Derived	16
9	Availability of more adequate exitway	Input	
10	Front of building	Input	
11	Projecting beyond building line	Input	
12	Height of lowest landing above grade	Input	
13	Counterbalanced stair to street	Input	
14	Fixed ladder to roof	Input	
15	Alley or thoroughfare less than 30 feet wide	Input	
16	Design live load	Input	
17	Steel or other noncombustible material	Input	
18	Wood not less than 2 inches thick	Input	

Table 2.1 Datum list for fire escape example (concluded)

Reference Number	Title	Source	Ingredient Data Items
19	Type of construction	Input	
20	Fire district	Input	
21	Stair width	Input	
22	Riser height	Input	
23	Tread width	Input	
24	Landing width	Input	
25	Landing length	Input	
26	Landing distance below access	Input	
27	Hour opening protective	Input	
28	Within fire limits	Input	
29	Requirement for landing clearance	Derived	10,11,12,13,14,15, 26
30	Requirement for material type	Derived	6,7,17,18,19,20,28, 32,33
31	Requirement for stair dimensions	Derived	21,22,23
32	Number of occupants	Input	
33	Wood or similarly combustible material	Input	
34	Requirement for fire rating of doors and windows	Derived	2,27
35	Requirement for landing dimensions	Derived	24,25

Table 2.2 Requirement for permission to use fire escapes (datum number 1)

		1	2	E
1	Use group L2 or L3 (2)	T	F	
2	Special order of building official (3) AND existing building (4) AND height not greater than 5 stories (6) AND height not greater than 65 feet (7) AND more adequate exitway impossible (9)	.	T	
1	Requirement = satisfied	X	X	
2	Requirement = violated			X

Table 2.3 Requirement for design load of fire escapes (datum number 8)

		1	2
1	Design live load ≥ 100 psf (16)	T	F
1	Requirement = satisfied	X	
2	Requirement = violated		X

Table 2.4 Requirement for landing clearance (datum number 29)

		1	2	3	4	5	6	E
1	Front of building (10)	T	T	F	F	T	F	
2	Projecting beyond building line (11)	T	F	.	.	T	.	
3	Counterbalanced stair to street (13) AND fixed ladder to roof (14) AND 10 ft ≤ height of lowest landing (12) ≤ 14 ft	T	.	.	.	F	.	
4	Alley or thoroughfare < 30 ft wide (15)	F	.	T	F	.	T	
5	Height of lowest landing (12) ≥ 14 ft	.	.	T	.	.	F	
6	Landing dist. below access (26) ≤ 8 in	T	T	T	T	.	.	
1	Requirement = satisfied	X	X	X	X			
2	Requirement = violated					X	X	X

Table 2.5 Requirement for material type (datum number 30)

		1	2	3	4	5	E
1	Steel or other noncombustible material (17)	T	-	-	-	-	
2	Within fire limits (24)	.	F	F	T	T	
3	Height ≤ 3 stories (6) AND height ≤ 40 feet (7) AND number of occupants ≤ 20 (32)	.	T	F	.	.	
4	Wood or similarly combustible material (33)	-	T	T	T	T	
5	Within fire district 2 (20) AND type 3 or type 4 construction (19) AND wood ≤ 2 inches thick (18) AND height ≤ 3 stories (6)	.	.	.	T	F	
1	Requirement = satisfied	X	X		X		
2	Requirement = violated			X		X	X

Table 2.6 Requirement for stair dimensions (datum number 31)

		1	E
1	Stair width (21) ≥ 22 in	T	
2	Riser height (22) ≤ 8 in	T	
3	Tread width (23) ≥ 8 in	T	
1	Requirement = satisfied	X	
2	Requirement = violated		X

Table 2.7 Requirement for fire rating of doors and windows (datum number 34)

		1	2	3
1	Use group L2 or L3 (2)	T	F	F
2	Fire rating of doors and windows ≥ 3/4 hr (27)	·	T	F
1	Requirement = satisfied	X	X	
2	Requirement = violated			X

Table 2.8 Requirement for landing dimensions (datum number 35)

		1	E
1	Landing width ≥ 40 in (24)	T	
2	Landing width ≥ 36 in (25)	T	
1	Requirement = satisfied	X	
2	Requirement = violated		X

and actions and the vertical columns of rules are numbered in each decision table for reference purposes.

A simple nomenclature is used in the decision tables. A "T" or "Y" in a condition entry indicates that the condition must be true for the particular rule to apply. An "F" or "N" in a condition entry indicates that the condition must be false. An "I" or "." in a condition entry indicates the condition is immaterial; it can be either true or false. A "-" in a condition entry indicates the condition is implicitly false because of another condition, and a "+" indicates the condition is implicitly true. An "X" in an action entry indicates which action is to be taken for a given rule.

Tables 2.2, 2.4, 2.5, 2.6, and 2.8 have a last rule labeled "E" (for Else) that is matched by any combination of conditions not matched by any preceding rules. The action corresponding to an else rule is either the issuance of an error message (if the combination of conditions is impossible) or the assignment of "violated" to the datum corresponding to the table (if the combination of conditions is unacceptable).

The numerals in parentheses in the condition stubs of the decision tables are the reference numbers of the data items that must be known in order to evaluate the particular condition. Each datum referenced in a condition stub is an <u>ingredient</u> of the datum defined by the action. The latter datum is termed a <u>dependent</u> of each of its ingredients.

Table 2.2 illustrates most of this decision table nomenclature. In this table, rule 1 applies if condition 1 is true since condition 2 is then immaterial; action 1 is taken. Only ingredient datum 2 had to be known in order to determine that rule 1 applies and to evaluate the dependent datum. If condition 1 is false and condition 2 is true, rule 2 applies, and action 1 also is taken. For all other combinations (here, only one), the else rule applies, and action 2 is taken. Ingredient data items 3,4,6,7, and 9 had to be known in addition to datum 2 to determine which of rule 2 and the else rule applies and to evaluate the dependent datum.

A <u>decision tree</u> can be generated from the logic represented in a decision table to explore the significance of the else rule. The decision tree corresponding to table 2.5 is shown in figure 2.2. Each of the else rules in the decision tree represents a combination of conditions not covered by a rule in the decision table. Each such combination can be checked to determine whether it is feasible and should have an explicit rule and action. The else rules found in figure 2.2 turn out to be infeasible--they describe a material that is neither combustible nor noncombustible.

2.1.4 Information Network

The ingredient data items are those whose values must be known in order to evaluate the dependent. For example, datum 1, Requirement for the Use of Fire Escapes, has ingredient data items 2, 3, 4, 6, 7, and 9, as shown by tables 2.1 and 2.2. The set of ingredient data items is called the <u>ingredience</u> of the dependent. Similarly, the set of data items dependent on an

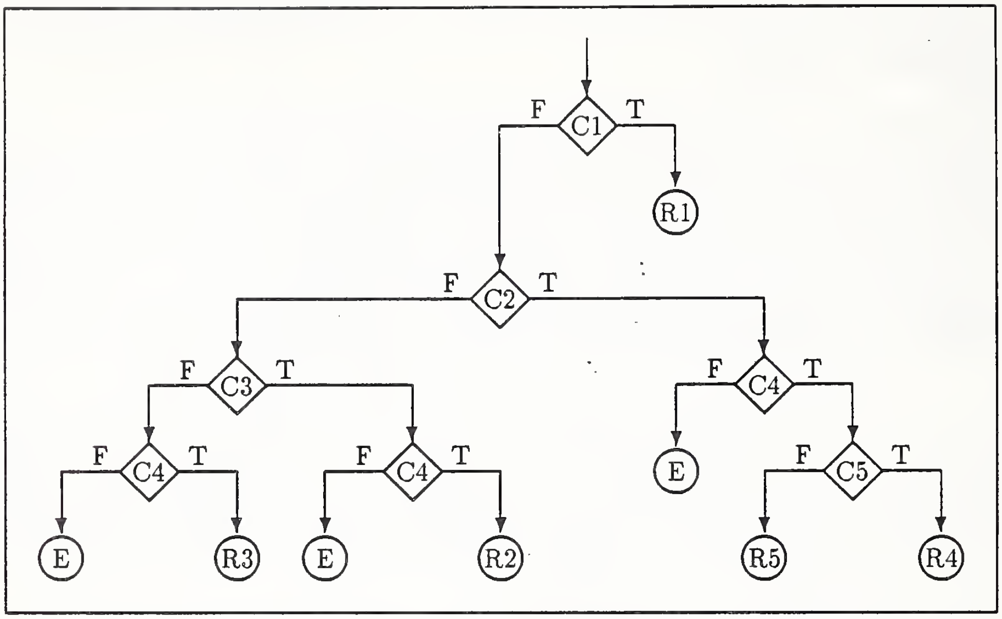

Figure 2.2 Decision tree for the logic in table 2.5. Logical tests of conditions are shown as diamonds with "T" and "F" labelling the branches corresponding to true and false values of the condition tested.

ingredient datum is called its <u>dependence</u>. For example, datum 2, Use Group, has dependents 1 and 34, as shown by tables 2.1, 2.2, and 2.7.

An <u>information network</u> is used to represent the precedence relations among the data items in the standard. Each datum corresponds to a node in the network and branches are drawn from each ingredient to its dependent datum(s). The information network graphically represents the flow of information through the data items and the decision points in the set of provisions. Figure 2.3 shows a portion of the information network for the fire escape example. This particular example leads to a shallow, straightforward network. Many standards lead to complex networks many levels deep. It should be apparent that, irrespective of its complexity, the entire information network can be assembled once each datum and its direct ingredients are known.

2.1.5 Classification System

A classification system based on a model structure for provisions [9] is used to generate outlines, organizations, and indices that represent the arrangement and scope of the standard. All requirements as well as any determinations that are likely to be referred to directly by users must be classified.

The model structure of a requirement includes two parts, a subject and a predicate. The subject may be a physical entity (for instance, a part of a

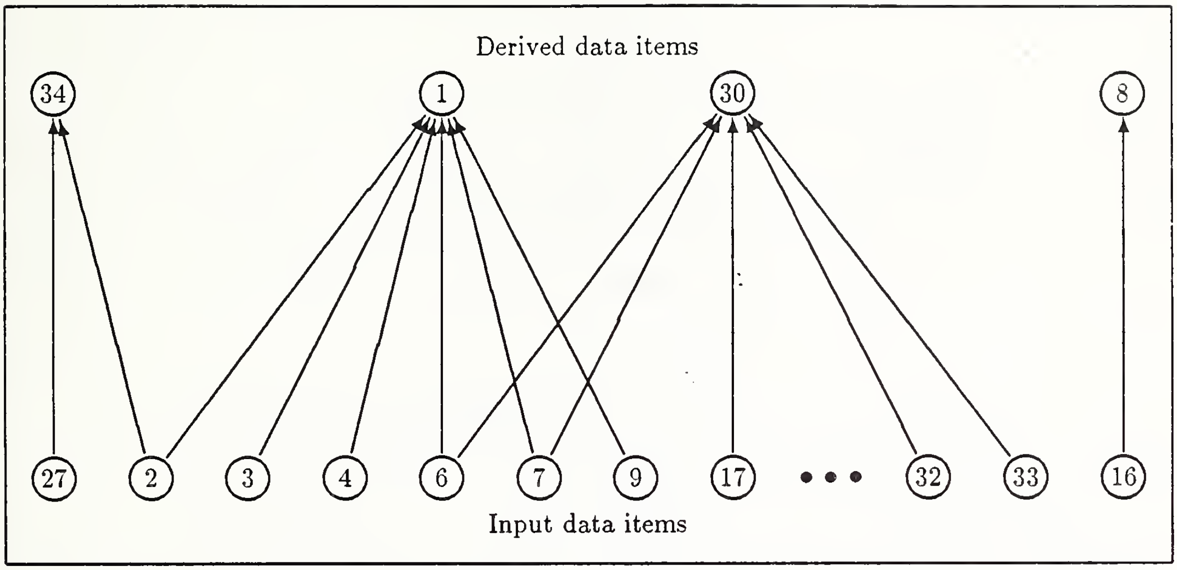

Figure 2.3 Portion of information network for the fire escape example

building), a process (for example, design or manufacture), or a participant in the process (for example, a designer, builder, or regulatory agency). The predicate is a particular quality or action required of a subject (for instance, strength or stiffness of a building part or submission of quality assurance documents from a manufacturer). The classification system for a standard, then, is based on the names, called classifiers, of all of the subjects and predicates covered by its privision.

The classifiers for the fire escape example are listed in table 2.9. They were selected by naming the subject and predicate of each of the requirements shown in table 2.1.

The list of classifiers pertaining to a particular provision is called the argument list of that provision, as is the collection of lists for all the provisions. The argument list for the fire escape example is given in table 2.10. The list of provisions coming under a particular classifier is called the scopelist of that classifier, as is the collection of lists for all the classifiers. The scopelist for the fire escape example is shown in table 2.11. The scopelist can be generated by transposing the argument lists for all the provisions. The use of these lists is discussed in Chapter 4.

Once selected, the classifiers are systematically organized into a hierarchy to represent the successively finer subdivisions of the subjects and the required qualities (predicates) falling within the scope of a standard. Figure 2.4 provides one possible hierarchy of classifiers for the fire escape example with one field for subjects under the principal heading "building" and another field for predicates under the principal heading "acceptability." The hierarchy of a major standard may involve many fields.

Table 2.9 Classifier list for the fire escape example

(a) Subjects

Reference Number	Title
1	Fire escape
2	Landing
3	Material
4	Doors and windows
11	Components
12	Stairs
13	Mechanical parts
14	Apertures
17	Building

(b) Predicates

Reference Number	Title
5	Permitted usage
6	Design strength
7	Clearance
8	Combustibility
9	Dimensions
10	Fire rating
15	Live loads
16	Dead loads
18	Acceptability

Table 2.10 Argument list for the fire escape example

Provision	Classifier
1 Requirement for permission to use fire escapes	1 Fire escape 5 Permitted usage
8 Requirement for design load of fire escapes	1 Fire escape 15 Live loads
29 Requirement for landing clearance	2 Landing 7 Clearance
30 Requirement for material type	3 Material 8 Combustibility
31 Requirement for stair dimensions	9 Dimensions 12 Stairs
34 Requirement for fire rating of doors and windows	4 Doors and windows 10 Fire rating
35 Requirement for landing dimensions	2 Landing 9 Dimensions

Table 2.11 Scopelist for the fire escape example

Classifier	Provision
1 Fire escape	1 Requirement for permission to use fire escapes 8 Requirement for design load of fire escapes
2 Landing	29 Requirement for landing clearance 35 Requirement for landing dimensions
3 Material	30 Requirement for material type
4 Doors and windows	34 Requirement for fire rating of doors and windows
5 Permitted usage	1 Requirement for permission to use fire escapes
6 Design strength	
7 Clearance	29 Requirement for landing clearance
8 Combustibility	30 Requirement for material type
9 Dimensions	31 Requirement for stair dimensions 35 Requirement for landing dimensions
10 Fire rating	34 Requirement for fire rating of doors and windows
11 Components	
12 Stairs	31 Requirement for stair dimensions
13 Mechanical parts	
14 Apertures	
15 Live loads	8 Requirement for design load of fire escape
16 Dead loads	
17 Building	
18 Acceptability	

<u>Subject field</u>

Building

- Fire escape
  - Material
  - Components
    - Landing
    - Stairs
    - Mechanical parts
- Apertures
  - Doors and windows

<u>Predicate field</u>

Acceptability

- Permitted usage
- Design strength
  - Live loads
  - Dead loads
- Combustibility
- Dimensions
  - Clearance
- Fire rating

Figure 2.4 A hierarchy of classifiers for the fire escape example

The subject and predicate fields in the classifier hierarchy are combined to generate three related representations of possible arrangements of a standard. An organization is a tabular arrangement of headings, each heading corresponding to a specific classifier. A possible organization for the fire escape example is shown in figure 2.5.

An outline contains, in addition to the headings, the pertinent provisions classified under the selected heading. An outline for the fire escape example is shown in figure 2.6. As an illustration of the use of an outline (along with the decision tables for the provisions) in the expression of a standard, new text has been generated for the fire escape example from the outline in figure 2.6. The new text is given in figure 2.7.

Finally, an index provides an alphabetized listing of classifiers, with a listing of the scopelist of each classifier, that is, of the provisions associated with each classifier. An index for the fire escape example would be a trivial reordering of table 2.11 and isn't shown.

2.2 The SASE Program

2.2.1 SASE Program Summary

The SASE program is an integrated collection of computer aids for the analysis, synthesis, and expression of standards. The salient features of the SASE program are:

- integration of all functions into a single system;
- maintenance of all information in a database, thus providing facilities to store, analyze, modify, and combine information about versions of a standard as it progresses through its "life cycle" of initial formulation, revisions, modification, adoption, and maintenance;
- convenient user interaction for entry, analysis, modification, and display geared to users with varying levels of proficiency;
- facilities for processing and combining large standards subdivided into several units, which may be analyzed or synthesized by different groups of experts or analysts; and
- facilities for interfacing with additional capabilities, including text generation and computer-aided design, to be developed in the future.

The SASE program provides the following major functions to the analyst:

- data management for storage and maintenance of the information contained in a standard;
- analysis to check decision table representations of provisions of a standard for uniqueness and completeness;

I. Fire escape

   A. Permitted usage
      1. Material
      2. Components

   B. Dimensions
      1. Material
      2. Components
         a. Landing
            i. Clearance
         b. Stairs
            i. Clearance
         c. Mechanical parts
            i. Clearance

   C. Design strength
      1. Live loads
         a. Material
         b. Components
      2. Dead loads
         a. Material
         b. Components

   D. Combustibility
      1. Material
      2. Components

II. Apertures

   A. Fire rating
      1. Doors and windows

Figure 2.5 An organization for the fire escape example generated from the hierarchy in figure 2.4.

I. Fire escape

- A. Permitted usage
  - \- Requirement for permission to use fire escapes
  - 1. Material
  - 2. Components

- B. Dimensions
  - 1. Material
  - 2. Components
    - a. Landing
      - \- Requirement for landing dimensions
      - i. Clearance
        - \- Requirement for landing clearance
    - b. Stairs
      - \- Requirement for stair dimensions
      - i. Clearance
    - c. Mechanical parts
      - i. Clearance

- C. Design strength
  - 1. Live loads
    - \- Requirement for design load of fire escape
    - a. Material
    - b. Components
  - 2. Dead loads
    - a. Material
    - b. Components

- D. Combustibility
  - 1. Material
    - \- Requirement for material type
  - 2. Components

II. Apertures

- A. Fire rating
  - 1. Doors and windows
    - \- Requirement for fire rating of doors and windows

Figure 2.6 An outline for the fire escape example corresponding to the organization in figure 2.5.

SECTION 623.0: FIRE ESCAPE

623.1 Permitted Usage

Fire escapes are unconditionally permitted in use groups L2 and L3 (one- and two-family and multi-family dwellings). In all other use groups, fire escapes are permitted only on existing buildings with height of not more than 5 stories and not more than 65 feet, and only if more adequate exit ways do not exist, by special order of the building official.

623.2 Dimensions

623.21 Landings. No landing shall be less than 40 inches wide and 36 inches long. No landing shall be more than 8 inches below the bottom of an access window or door. Lowest landings which project beyond the front building line shall have counterbalanced stairways to the street, fixed ladders to the roof, and shall be between 10 and 14 feet, inclusive, above the street. Lowest landings in alleyways or thoroughfares less 30 feet wide shall not be less than 14 feet above the alley or thoroughfare.

623.22 Stairs. Stairs shall be not less than 22 inches wide, with risers not greater than 8 inches and treads not less than 8 inches.

623.3 Design Strength

The fire escape shall be designed to support a minimum live load of 100 psf.

623.4 Combustibility

Steel or other noncombustible materials are unconditionally acceptable for the fabrication of fire escapes. Wood or other combustible materials are acceptable for the fabrication of fire escapes outside the fire limits if the building height is not greater than 3 stories and not greater than 40 feet, and if the occupant load is not greater than 20 persons. Wood at least 2 inches thick is acceptable for the fabrication of fire escapes within the fire limits if the building is within Fire District 2, is of type 3 or type 4 construction, and has a height not greater than 3 stories.

623.5 Fire Rating of Building Aperture

For use groups other than L2 or L3, the fire rating of doors and windows providing access to fire escapes must be at least 3/4 hour.

Figure 2.7 New text for the fire escape example generated from the outline in figure 2.6.

- information network model which enables the evaluation of relations among provisions of a standard and provides checks to ensure that these relations are connected and acyclic;

- organization model which permits the exploration of alternative ways of organizing a standard without losing information contained in the document or changing the standard's meaning; and

- index generator which extracts information from a given organization of a standard.

2.2.2 SASE Database Organization

The components of standards represented in SASE are called entities. The entities are organized into three groups, according to type, and each group has an associated set of commands specifying the actions to be performed on the designated entities.

Each entity is defined by the value of a set of attributes, one of which serves as the reference (or key) for uniquely identifying a specific entity.

The three groups are briefly discussed below. In the discussion, reserved words in the SASE program, such as entity names, attribute labels, and commands are shown in capital letters.

Organizational Entities. This group of entities refers to the global organizing elements in the SASE database, and includes:

- STANDARD - the specific standard currently under consideration;

- VERSION - a particular stage of a standard (e.g., original, trial, modification, adopted, etc.) and

- CHAPTER - a major subdivision of the current version.

Organizational entities are identified by name and contain attributes such as title and description.

The SASE commands applicable to organizational entities are:

- CREATE a new entity;

- USE a previously defined entity;

- ADD, MODIFY, AND DELETE attributes;

- LIST entities currently in database; and

- DESTROY an entity.

Basic Entities. This group of entities contains the detailed information about a standard, and includes:

- DATUM - representing individual data items;
- TABLE - representing individual decision tables;
- FUNCTION - representing functions; and
- CLASSIFIER - representing individual classifiers.

DATUM and CLASSIFIER entities are identified by a reference number. TABLE and FUNCTION entities are identified by the reference number of their corresponding DATUM. The specific attributes of each entity are discussed in the following chapters.

The SASE commands applicable to this class of entities are:

- ENTER an initial definition;
- ADD, MODIFY, OR DELETE attributes;
- DISPLAY an entity or set of entities;
- DELETE an entity.

Derived Entities. This group contains entities generated from the basic entities, and includes:

- TREE generated from a decision table;
- NETWORK generated from the data items;
- HIERARCHY generated from the classifiers;
- SCOPELIST generated from the hierarchy and data items;
- INDEX generated from the scopelist;
- ORGANIZATION generated from the classifiers;
- OUTLINE generated from the classifiers and data items.

ORGANIZATION entities are identified by a reference number. TREE entities are identified by the reference number of the decision tables from which they are generated. The other entities in this group do not have a reference, as (in the present version of SASE) only one entity of each type can exist at any one time in a VERSION of a standard.

The SASE commands applicable to this group are:

- GENERATE to derive the entity;

- DISPLAY the entity;

- DELETE the entity.

In addition, an ORGANIZATION may be initially ENTERed by the user instead of being GENERATEd at the same time as its associated OUTLINE. Because the construction of satisfactory ORGANIZATIONs and OUTLINEs is a complex process, interactive dialog modes are made available to the user including the ability to interrupt and then CONTINUE their entry.

The hierarchical relationships among the entities in the SASE database is shown in figure 2.8.

The combinations of command/entity pairs available in the SASE program are shown in table 2.12.

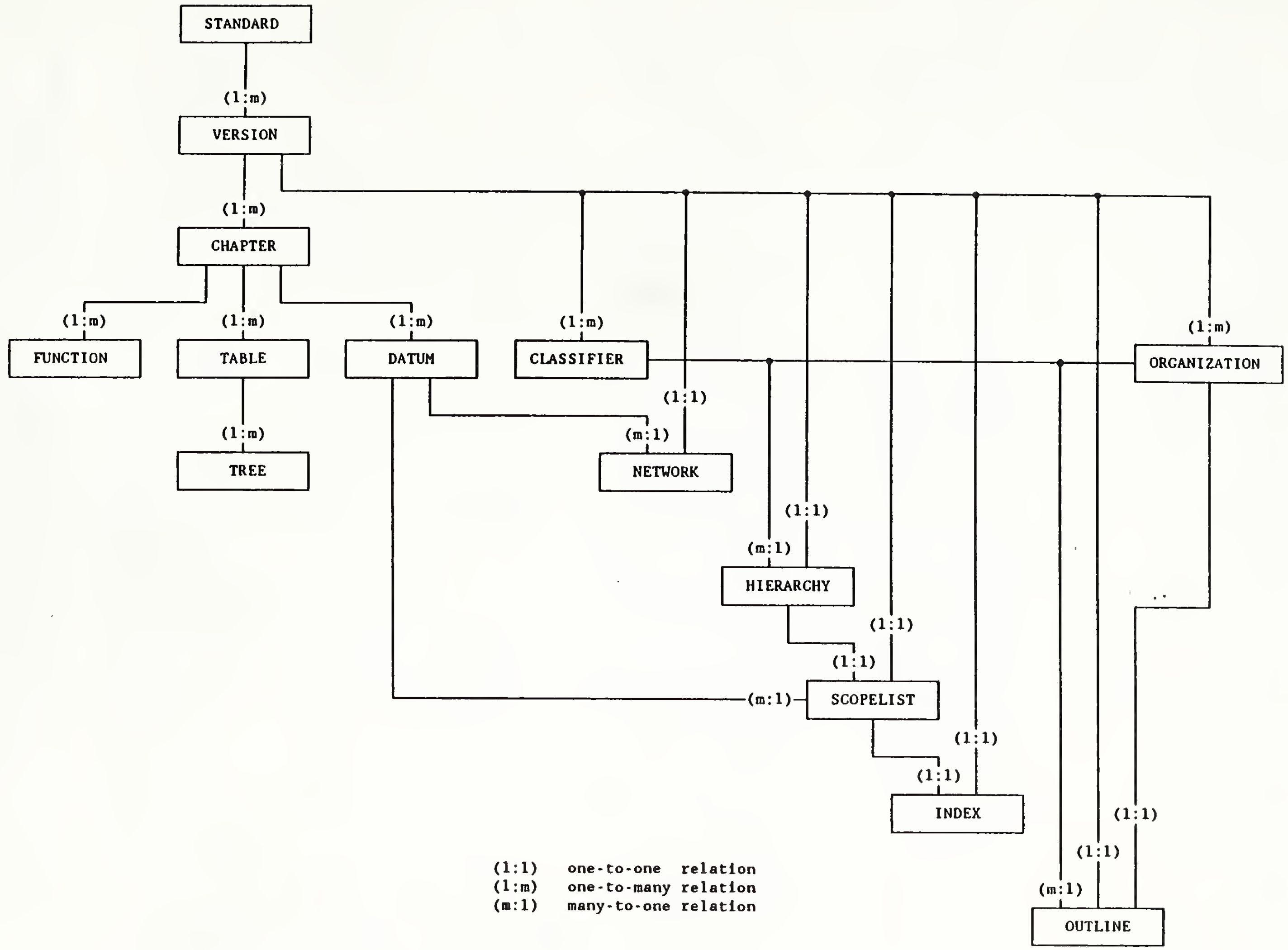

Figure 2.8 Organization of the SASE Database

Table 2.12 Available SASE command/entity combinations

Entities	CREATE (create)	ENTER (create)	GENERATE (create)	ADD (change)	MODIFY (change)	RESEQUENCE (change)	CONTINUE (change)	USE (examine)	LIST (examine)	DISPLAY (examine)	DESTROY (remove)	DELETE (remove)
(organizational)												
STANDARD	X			X	X[1]			X	X		X	X[1]
VERSION	X			X	X			X	X		X	X
CHAPTER	X			X	X			X	X		X	X
(basic)												
DATUM		X		X	X	X				X		X
TABLE		X		X	X	X				X		X
FUNCTION		X		X	X					X		X
CLASSIFIER		X		X	X	X				X		X
(derived)												
TREE			X							X		X
NETWORK			X							X		X
HIERARCHY			X							X		X
SCOPELIST			X							X		X
INDEX			X							X		X
ORGANIZATION		X			X		X			X		X
OUTLINE			X				X			X		X

[1]Only non-key attributes can be modified or deleted.

3. MODELLING THE INFORMATION OF A STANDARD

This chapter presents the SASE techniques for modelling the information of a standard. The model is essentially independent of the organization and expression of the information. Major sections are: Data Items, Provisions, Decision Tables, Decision Trees, Functions, and Networks. The reader is encouraged to examine the Appendix A, which presents an example to illustrate the application of these techniques to a standard.

3.1 Data Items

3.1.1 Definition

A data item or datum is an information element occurring in a standard. Conventionally, a standard contains a list of definitions of key information elements and a table of nomenclature for information elements identified by symbols. All these information elements are identified as data items in SASE. For a complete representation, SASE typically requires many additional data items not normally included in definitions or the table of symbols.

The identification of data items representing the information content of a standard is somewhat analogous to the parsing of sentences. The identification of significant information elements to be designated as data items has to be guided by the analyst's experience and "feel" for the intent and scope of the standard being analyzed. It is best to approach this task incrementally, initially identifying only obvious key data items, and then supplementing these as the analysis proceeds in depth.

3.1.2 Proper Usage

The selection of data items must be guided by the analyst's experience and judgment. The following suggestions may be of assistance.

Granularity. New users of SASE have a tendency to identify more data items than necessary for describing the intent and content of a standard. It is important to use the right "granularity" and identify only the meaningful data items. Additional items can always be entered later, say, when a detailed decision table analysis identifies additional ingredients.

Existence-type items. It is easy to overlook Boolean data items specifying a true or false quantity, such as the existence of a particular object or state. Thus, to represent the sentence: "If stiffeners are provided and they are spaced ...", a Boolean data item, "stiffeners provided" is needed in addition to the numeric data item "stiffener spacing".

Options and alternatives. Standards frequently contain words such as "optionally", "preferably" or "alternately", indicating user choices. It is important to identify each of these as individual Boolean data items, with appropriate titles such as "option desired" or "alternate exercised".

Regulatory options. Similar to the above, standards contain statements such as "building official may require", "values satisfactory to the building official," etc. All such options must again be identified as specific data items, with appropriate titles such as "required by building official" or "acceptable to building official."

Use of Boolean vectors. Compactness and clarity of representation can be achieved by the use of Boolean vectors instead of separate individual Boolean data items. Thus, a single data item "building type" with possible values of "new" and "existing" is preferable to two separate Boolean data items. Boolean vectors can be extended to more than two entries, such as a "building category" item with possible values of "A", "B", "C", or "D". Data items such as "load type" and "element type" fall into this category. It will be seen in section 3.3 that many of the conditions in decision tables are directly in the form of "Boolean vector datum = one of its possible values". It is good practice to use the COMMENT field to record the possible values of a Boolean vector datum.

3.1.3 Representation

Each data item is represented in SASE by a datum entity. The attributes describing a datum are discussed below.

REFERENCE NUMBER. The reference number is a numeric key for identifying the datum. The reference number must be unique within a version. A convenient identification scheme is to use a five-digit reference number, the first two digits referring to the chapter and the last three digits sequentially assigned within the chapter in increments of 10, thereby providing space for reference numbers for data items to be inserted later.

NAME. Any short, mnemonically meaningful alphabetic designation. While this attribute can be useful now as a memory aid to the analyst, its primary use will be in executable computer programs that represent the standard.

TITLE. Any descriptive title of the datum entered, as a text string. Its most common use is in the preparation of the index.

SECTION. The alphanumeric designation of the section in the existing standard. This and the PAGE attribute are used for cross-referencing to the text of an existing standard.

PAGE. The page number in the existing standard.

VALUE. This attribute defines the kind of value used for expressing the data item, and can be one of the following:

- NUMERIC, meaning that the data item is expressed as a number;
- BOOLEAN, meaning that the data item is a fact (a true or false quantity); or

- BV for Boolean vector, meaning that the data item can take on a value from a fixed list or vector of distinct names or numbers.

SOURCE. Designates whether the datum is INPUT or DERIVED from other data items. This and the following three attributes relate to the position of the datum in the information network, which will be discussed further in section 3.2 through 3.6.

TYPE. If the datum is DERIVED, this attribute designates whether the derivation is by means of a decision TABLE (see section 3.3) or a FUNCTION (see section 3.5).

UTILIZATION. If the datum is DERIVED, this attribute designates whether the datum is a REQUIREMENT or a DETERMINATION (see section 3.2).

INGREDIENTS. If the datum is DERIVED, the list of ingredient data items is given, identified by their datum reference numbers.

STATUS. Designates whether the datum is CLASSIFIED or UNCLASSIFIED. This and the ARGUMENT attribute relate to the position of the datum in the classification hierarchy, which is discussed in Chapter 4.

ARGUMENTS. If the datum is CLASSIFIED, the list of its classifiers is given, identified by their classifier reference numbers. The argument list may be preceded by the words INDEX or OUTLINE, designating that the datum be included in the index or outline only.

EQUIVALENTS. In the analysis of existing standards, the situation frequently arises where the text uses a variety of names for what is actually a single thing. Such equivalents initially can be cross-referenced by their datum reference numbers as they are detected and the duplication subsequently eliminated.

COMMENT. Any descriptive information or comment may be entered as a text string.

3.2 Provisions

3.2.1 Definition

Provisions are the basic units of a standard. Each provision is a normative statement, stipulating that some object or process within the scope of the standard is to have a certain quality or property.

Provisions are distinguished by their use:

- Requirements are provisions that directly determine compliance with the standard; they are Boolean valued, with the values of true or false interpreted as satisfied or violated, respectively; while

- Determinations are all other provisions; these may include numerical, nominal, and Boolean valued items which can not be characterized as satisfied or violated.

Requirements contain two basic components: a subject and a predicate. The subject is a physical entity, a process or a participant in the process, and the predicate defines the particular quality required of the subject.

Requirements play a key role in the SASE methodology. On the one hand, they are the highest nodes of the information network (see section 3.6): the information network traces the data items, which when evaluated, determine whether the stipulations of the standard are satisfied or not. On the other hand, requirements are the lowest nodes of the classification system (see Chapter 4): the hierarchy of classifiers defining the scope and organization of the standard is built up from the "elementary" classifiers defining the subjects and predicates of the requirements.

Harris and Wright [9] define six types of requirements:

- Basic requirements have a singular subject and a singular predicate. They do not directly depend on other requirements.

- Multiple requirements have plural subject and/or predicates. They do not directly depend on other requirements.

- Cumulative requirements depend unconditionally only on other requirement data items. The logic of the provision does not contain any original requirements.

- Application requirements depend conditionally on at least one of the ingredient requirements. The provision does not contain an original requirement, nor is it equivalent to a new basic requirement.

- Synthetic requirements are like application requirements except that they are equivalent to a new basic requirement.

- Mixed requirements depend directly on other requirements (either conditionally or unconditionally) and the provision does contain an original statement of a requirement.

3.2.2 Proper Usage

<u>In synthesis.</u> In synthesizing a new or revised standard, it is important not to constrain the organizational system from developing alternative arrangements based on the classifier hierarchy. Therefore, it is recommended that [9]:

- Mixed requirements not be used;

- Cumulative requirements not be used;

- Multiple Requirements be used only in those instances in which the constituent basic requirements would be most likely to remain together in all practicable arrangements, and then only with caution; and

- Application requirements that simply group ingredient requirements not be used.

In analysis. In analyzing or representing an existing standard, it will be frequently found that individual requirements are lumped together, i.e., that a section or even a single existing provision may contain several unrelated individual requirements. The analyst may be tempted to create one or more cumulative requirements to express all the requirements of the section or original provision. This practice is to be avoided because cumulative requirements constrain the exploration of alternative arrangements; also, cumulative requirements will be difficult to classify by the procedures described in Chapter 4.

3.2.3 Representation

In SASE, provisions are represented by the data items that carry the value of the provision. Data items representing provisions are distinguished by the following attribute values:

- SOURCE is DERIVED, since, by definition, the value of the provision must be derived from the values of other ingredient data items;

- TYPE is either TABLE or FUNCTION, depending on how the logic of derivation is expressed;

- UTILIZATION is either REQUIREMENT or DETERMINATION; and

- the list of INGREDIENTS is non-empty.

Furthermore, all requirements, as well as many key determinations, will have non-empty lists of ARGUMENTS since they are to be located using the classification system.

3.3 Decision Tables

3.3.1 Definition

Decision tables are used to represent and examine the logical structure of individual requirements in a standard. They may also be used for all other data items whose value is derived by procedures or rules described in the standard. The following discussion begins with a general description of decision tables before arriving at the specific form of decision tables used in SASE.

General. A decision table defines a set of rules specifying certain actions to be executed based on a specific set of conditions. Decision tables are a convenient means to express the logic for a set of decisions.

Decision tables were developed in the late 1950's to describe logical problems for computer programming when flow charting proved to be too complex and cumbersome. Decision tables have met with success because they require an overall analysis of situations involving parallel thought processes. Written text and, to some extent flow charts, both describe sequential thought patterns. References [14, 11] contain general information on decision tables.

A decision table is composed of conditions, actions, and rules. A condition is a logical statement that may have only one of two values: true or false. An action in a general sense is any operation, e.g., it may be the assignment of a value to a variable by means of a formula, or a statement that prescribes a set of conditions in order that a specified set of actions can be performed. A decision table is a structure for defining a set of related rules. The conventional structure of a decision table is shown in table 3.1.

The condition stub lists each condition in the table, one to a row. The action stub does the same for the actions. The condition entry lists the combinations of values of the conditions, one set to a column. Each column in the condition entry defines a rule. The action entry indicates which actions are to be executed for each rule. The rule is a logical AND function, that is, the rule is not satisfied unless each of the condition entries it contains is matched.

<u>Extended Entry Tables.</u> The most general form of decision table is known as an extended entry table. The statements contained in the stubs of these tables are generally incomplete, in that the stub and an entry value together make a complete statement. This form of decision table is very flexible and is readily interpreted by readers. Many tables in existing standards are essentially of this type, although the physical arrangement is generally not as shown in table 3.1. For example, consider a sample provision taken from [15] and shown in table 3.2.

Table 3.1 Regions of a decision table

Condition stub	Condition entry
Action stub	Action entry

Table 3.2 Sample provision

Specific minimum yield point of lowest strength steel being joined	Electrode classification ASTM	Permissible stress in shear on throat of fillet or plug welds
≤ 36 ksi	A233E60	13.6 ksi
> 36 ksi but ≤ 50 ksi	A233E60	13.6 ksi
	A233E70	15.8 ksi
> 50 ksi	A316E70	15.8 ksi
	A326E80	17.7 ksi

In this example, the first two columns correspond to conditions, the third column corresponds to an action, and the rows correspond to rules. This same information is rewritten as an extended entry decision table in table 3.3.

In many standards, ingenious table formats have been devised to represent the logic associated with a particular decision when a narrative description is not practical. However, the tables become hard to interpret when more than two or three conditions are involved. Extended entry decision tables are by no means new or unique, but the formal structure that allows the combination of many conditions was not developed fully until the 1950's [14].

<u>Limited Entry Tables.</u> Primarily because they are so flexible, extended entry decision tables do not lend themselves to a routine analysis of their logic, and are difficult for computer programs to interpret automatically. A more widely used form of decision table, the limited entry form, avoids these problems. The condition stub of limited entry tables contains only complete logical statements which can have values of true or false. The

Table 3.3 Extended entry decision table

Minimum yield point of lowest strength steel is	≤36 ksi	>36 but ≤50 ksi	>36 but ≤50 ksi	>50 ksi	>50 ksi
ASTM electrode is	A233E60	A233E60	A233E70	A316E70	A316E80
Permissible shear stress =	13.6 ksi	13.6 ksi	15.8 ksi	15.8 ksi	17.7 ksi

condition entry contains only the values of the conditions (true or false) and the action entry contains an "X" if an action is to be executed or a blank if not. An elementary extension of the concept allows the use of an immaterial entry in the condition entry, which means that the particular rule does not depend on the value of the condition for the row with the immaterial entry. Conventional symbols used in limited entry tables are: "T" or "Y" for true, "F" or "N" for false, and an "I", dot, or blank for immaterial in the condition entry; a blank or a dash for "don't execute" and an "X" for "execute" in the action entry.

Extended entry tables may be converted to limited entry tables in a straightforward manner. Table 3.4 contains the conversion of the extended entry table shown in table 3.3. The new table has the same number of rules as the original table, but considerably more conditions and actions. Each extended entry condition must be divided so that all of its possible responses can be covered by limited entry conditions. Thus, the first condition of table 3.3 is divided into two limited entry conditions that are capable of defining the three bounded ranges. The second condition of table 3.3 is divided into four limited entry conditions, one for each of the unique entries in the original condition.

<u>Preparation of Conditions, Actions, and Rules.</u> One of the keys to the successful use of decision tables in the analysis and synthesis of standards is the proper formulation of condition and action stubs. There are two fundamental principles for the use of decision tables to represent provisions of standards.

The first principle is that each decision table establishes the value for only one data item. This restriction allows each decision table to be

Table 3.4 Limited entry decision table

$F_y \leq 36$ ksi	T	F	F	F	F
$F_y \leq 50$ ksi	T	T	T	F	F
A233E60	T	T	F	F	F
A233E70	F	F	T	F	F
A316E70	F	F	F	T	F
A316E80	F	F	F	F	T
$F_v = 13.6$ ksi	X	X			
$F_v = 15.8$ ksi			X	X	
$F_v = 17.7$ ksi					X

uniquely associated with one datum, which becomes a node in the information network, and it allows the ready determination of the ingredients of that node. The only allowable actions are those which establish a value for the data item associated with the decision table. All of the other data items used in the conditions and actions are the ingredients. While this principle restricts somewhat the great flexibility of decision tables, it does lead to a desirable consequence: the decision tables thus formed tend to be small and therefore easy to formulate, understand, and analyze.

The second principle is that, constants and operators aside, each condition stub and action stub contains only data items defined as nodes in the information network. This is necessary so that the information network can serve its function of providing access to all the necessary data items. This principle sounds elementary; however, some skill is required in formulating a standard such that the set of data items is consistent. Among the errors that occur are omission of data items, use of multiple names for the same item, and use of the same name for different items.

As an example of the formulation of conditions and actions for a decision table, consider another sample provision taken from [15] and presented in figure 3.1.

The provision deals entirely with the evaluation of one datum, the allowable stress, F_c. There are four ingredients, variables that may affect the value of F_c:

- the yield stress, F_y;
- the width, w;
- the thickness, t; and
- the type of member (angle strut or other section).

The step by step procedure for formulation of a decision table is flexible. One approach is to write down first the easily identifiable actions:

1. $F_c = 0.60\ F_y$
2. F_c = given by formula 1
3. $F_c = 8{,}000/(w/t)^2$
4. $F_c = 19.8 - 0.29\ (w/t)$
5. F_c = given by formula 2

Note that the fifth action was found in a footnote of the cited reference.

From a first reading of the provision, it is clear that the width-thickness ratio, w/t, is very important and that several conditions will involve it.

3.2 Compression of Unstiffened Elements

Compression, F_c, in kips per square inch, on flat unstiffened elements:

(a) For $w/t \le 63.3/\sqrt{F_y}$: $F_c = 0.60F_y$

(b) For $63.3/\sqrt{F_y} < w/t \le 144/\sqrt{F_y}$:*

$$F_c = F_y[0.767 - (2.64/10^3)(w/t)\sqrt{F_y}] \qquad \text{Formula (1)}$$

(c) For $144/\sqrt{F_y} < w/t \le 25$:*

$$F_c = 8{,}000/(w/t)^2$$

(d) For $25 < w/t \le 60$:**

For angle struts:

$$F_c = 8{,}000/(w/t)^2$$

For all other sections:

$$F_c = 19.8 - 0.28(w/t)$$

In the above formulas, w/t = flat-width ratio as defined in section 2.2

---

*When the yield point of steel is less than 33 ksi, then for w/t ratios between $63.3/\sqrt{F_y}$ and 25:

$$F_c = 0.60F_y - \frac{[w/t - 63.3/\sqrt{F_y}](0.60F_y - 12.8)}{25(1 - 2.53/\sqrt{F_y})} \qquad \text{Formula (2)}$$

**Unstiffened compression elements having ratios of w/t exceeding approximately 30 may show noticeable distortion of the free edges under allowable compressive stress without detriment to the ability of the number to support load.
For ratios of w/t exceeding approximately 60 distortion of the flanges is likely to be so pronounced as to render the section structurally undesirable unless load and stress are limited to such a degree as to render such use uneconomical.

Figure 3.1 Sample provision

It is convenient to write related conditions in adjacent positions, as follows:

1. $w/t \leq 63.3/\sqrt{F_y}$

2. $w/t \leq 144/\sqrt{F_y}$

3. $w/t \leq 25$

4. $w/t \leq 60$

5. Member type = angle strut

The next step in the preparation of the table is to begin writing the rules, one rule at a time. The process is iterative, so the initial order of conditions and rules is not of paramount importance. The first three rules are easily identified: for rule one, condition one is true and the action is one; for rule two, condition one is false, condition two is true, and the action is two; for rule three, condition two is false, condition three is true, and the action is three. Choosing to ignore temporarily the first footnote, rules four and five can be formulated: for both rules, condition three is false and condition four is true; condition five is true for rule four and false for rule five while rule four uses action three and rule five uses action four.

In taking account of the first footnote, a new rule is formed which involves a new condition:

6. $F_y < 33$ ksi

For the sixth rule condition one is false, condition three is true, condition six is true, and the action is five. The decision table at this stage is shown in table 3.5.

At this point, one iteration in the formulation of the rules is complete. It should be emphasized that the blanks in the condition entry do not necessarily represent immaterial entries, because no consideration has been given to them yet. The conditions and actions can be seen to be in agreement with the stated principles of formulation. Completing the example will not add to the study of conditions and actions, but it is instructive in that it points out the manner in which decision tables demand full consideration of the situation being defined.

For rule one, condition two is obviously true if condition one is. Conditions three and four are not so obvious. A simple calculation indicates that condition three can be false when condition one is true only if $F_y < 6.4$ ksi, which is not only unlikely, but impossible if the material used meets the ASTM specifications referenced in [15]. For the sake of illustration, this information will be ignored, as if this one provision were analyzed in isolation. Therefore, conditions three and four will be immaterial for rule one. Conditions five and six also turn out to be immaterial for the rule.

Table 3.5 Initial condition entries

		1	2	3	4	5	6
1	$w/t \le 63.3/\sqrt{F_y}$	T	F				F
2	$w/t \le 144/\sqrt{F_y}$		T	F			
3	$w/t \le 25$			T	F	F	T
4	$w/t \le 60$				T	T	
5	Member strut = angle strut				T	F	
6	$F_y < 33$						T
1	$F_c = 0.6\ F_y$	X					
2	F_c = formula 1		X				
3	$F_c = 8000/(w/t)^2$			X	X		
4	$F_c = 19.8 - 0.28(w/t)$					X	
5	F_c = formula 2						X

For rule two, a similar analysis indicates that condition three could be false if F_y < 33 ksi. Since this is the situation defined in the footnote and covered in rule six, the entry for conditions three and four is true while that for condition six is false. Condition five is once again immaterial.

Rule three is completed using reasoning very similar to that for rule two. For rules four and five, the same limited analysis that was invoked on rule one is used again; consequently, the entries for conditions one, two, and six are immaterial for both rules.

For rule six, condition two may be either true or false so an immaterial entry is made. Condition four is true if condition three is, and condition five is immaterial. The completed table is shown in table 3.6.

Analysis of this table will show that rule one is not independent of either rule four or rule five. It can be determined from visual examination that the same set of condition values will satisfy rules one and four (for example: T, T, F, T, T, T), and that another set can be found for rules one and five. [A much easier way to determine this is to attempt to generate a decision tree (see section 3.4)]. As will be discussed further in the following, all rules in a decision table must be independent, therefore, some modification of the table is necessary. In this case, the information concerning the possible range of values for F_y must be taken

Table 3.6 Completed condition entries

		1	2	3	4	5	6
1	$w/t \leq 63.3/\sqrt{F_y}$	T	F	F	.	.	F
2	$w/t \leq 144/\sqrt{F_y}$	T	T	F	.	.	.
3	$w/t \leq 25$	.	T	T	F	F	T
4	$w/t \leq 60$	.	T	T	T	T	T
5	Member strut = angle strut	.	.	.	T	F	.
6	$F_y < 33$	.	F	F	.	.	T
1	$F_c = 0.6\ F_y$	X					
2	F_c = formula 1		X				
3	$F_c = 8000/(w/t)^2$			X	X		
4	$F_c = 19.8 - 0.28(w/t)$					X	
5	F_c = formula 2						X

into account. As pointed out, this would make condition three true for rule one. It would also make condition one false for rules four and five. For rule one, since condition three is true, condition four will be true also. The revised table is shown in table 3.7.

This completes the illustration of the development of the sample decision table. Decision trees derived from the various iterations in the development are shown in section 3.4.

<u>Contents of Condition and Action Stubs.</u> Typically, each condition stub consists of a single condition (true-false comparison) and each action consists of a single assignment expression or function. Both of these simple cases can be extended.

Several logical statements may be combined into one condition with the use of the logical functions AND and OR. Consider the hypothetical condition "A>B AND C>D AND E>F." The condition will be true if all portions of the condition are true, but it will be false if any one portion is false. If the AND operators in the example were replaced by the OR operator, the condition would then be true if any one portion were true, and it would be false only if all portions were false. Many provisions in standards are conveniently expressed using combined conditions. An example of their use is included at the end of this section.

Table 3.7 Revised condition entries (compare table 3.6)

		1	2	3	4	5	6
1	$w/t \le 63.3/\sqrt{F_y}$	T	F	F	F	F	F
2	$w/t \le 144/\sqrt{F_y}$	T	T	F	.	.	.
3	$w/t \le 25$	T	T	T	F	F	T
4	$w/t \le 60$	T	T	T	T	T	T
5	Member strut = angle strut	.	.	.	T	F	.
6	$F_y < 33$	.	F	F	.	.	T
1	$F_c = 0.6\ F_y$	X					
2	F_c = formula 1		X				
3	$F_c = 8000/(w/t)^2$			X	X		
4	$F_c = 19.8 - 0.28(w/t)$					X	
5	F_c = formula 2						X

Some decisions are appropriate to perform in the action stubs. As an example, consider a provision for allowable tension stress taken from [16] and shown in figure 3.2. The decision table for the determination of the allowable tension stress F_t is shown in table 3.8. The instruction to find the minimum or maximum of a group of variables is conveniently located as part of the action. Note, however, that logical operations included in the actions are not included in the decision tree or in any of the checks for

> On the net section, except at pin holes:
>
> $$F_t = 0.60F_y$$
>
> but not more than 0.5 times the minimum tensile strength of the steel.
> On the net section at pin holes in eyebars, pin-connected plates or built-up members:
>
> $$F_t = 0.45F_y$$
>
> For tension on threaded parts see Table 1.5.2.1.

Figure 3.2 Sample provision

Table 3.8 Decision table with compound actions

Location = pinhole	T	F
$F_t = 0.45\ F_y$	X	
$F_t = \min(0.60\ F_y,\ 0.50\ F_u)$		X

independent rules; therefore errors in their formulation are more difficult to detect.

The style of defining data items and of writing conditions and actions is an important consideration. A tendency exists immediately to write decision tables for requirements with only two actions, one for the yes value (satisfied) and one for the no value (violated). This may lead to decision tables that are large and difficult to analyze. When the analyst finds that a decision table is large (consisting of more than about ten rules), consideration should be given to redefining some of the ingredients, or to partitioning of the decision table. An example illustrating this point follows.

<u>Related Conditions and Implicit Entries.</u> Conditions that involve the same data item are related. In many cases, the value for one condition will predetermine the value of a related condition. Table 3.5 presents such a case because the four conditions concerning w/t are related. In rule one, the first condition is true; therefore, the second is also true because w/t cannot be both less than $63.3/\sqrt{F_y}$ and greater than $144/\sqrt{F_y}$. (The expansion of the entries permitted in a limited entry table allows such situation to be treated to advantage [14]). The two new condition entries needed to represent related conditions are implicitly true ,"+", and implicitly false, "-". They are used when the value of a condition for a rule is predetermined by the values of other conditions for that same rule. Thus, table 3.6 is transformed into table 3.9.

Besides conditions that compare a data item to bounded ranges, there are other types of conditions that are related. A common situation in standards is the comparison of a data item to the elements of a Boolean vector. The conditions concerning the type of electrodes is a mutually exclusive set, that is, only one of them may be used. Therefore, if any one of those four conditions is true, then the other three must be false. Table 3.4 is rewritten in table 3.10 taking account of the mutually exclusive set and of the relation between the conditions with F_y also.

Some sets of mutually exclusive conditions have another property: they are collectively exhaustive (the variable always takes one value from the set). When both properties hold, it is possible to write a rule in two equivalent ways with implicit entries. Consider the hypothetical variable x which must take a value from the mutually exclusive and collectively exhaustive set [A, B, C, D]. The three rules shown in table 3.11 are equivalent.

Table 3.9 Implicit entries (compare table 3.6)

		1	2	3	4	5	6
1	$w/t \leq 63.3/\sqrt{F_y}$	T	F	-	-	-	F
2	$w/t \leq 144/\sqrt{F_y}$	+	T	F	.	.	.
3	$w/t \leq 25$	+	+	T	F	F	T
4	$w/t \leq 60$	+	+	+	T	T	+
5	Member strut = angle strut	.	.	.	T	F	.
6	$F_y < 33$	.	F	F	.	.	T
1	$F_c = 0.6\ F_y$	X					
2	F_c = formula 1		X				
3	$F_c = 8000/(w/t)^2$			X	X		
4	$F_c = 19.8 - 0.28(w/t)$					X	
5	F_c = formula 2						X

Table 3.10 Implicit entries (compare table 3.4)

$F_y \leq 36$ ksi	T	F	F	-	-
$F_y \leq 50$ ksi	+	T	T	F	F
A233E60	T	T	-	-	-
A233E70	-	-	T	-	-
A316E70	-	-	-	T	-
A316E80	-	-	-	-	T
$F_v = 13.6$ ksi	X	X			
$F_v = 15.8$ ksi			X	X	
$F_v = 17.7$ ksi					X

Table 3.11 Equivalent rules

	1	2	3
x = A	F	-	F
x = B	T	T	+
x = C	F	-	F
x = D	F	-	F

Note that the set of electrode designators in table 3.10 is not collectively exhaustive because there are many more types of electrodes. It is possible that they could be made collectively exhaustive if another decision table were used to test the acceptability of the electrodes; the specification is not complete concerning this question [15].

Uniqueness. A very important principle in the theory of decision tables is that one rule and only one rule must be matched for any given set of variables that are used to define the conditions [14]. That is, the logical process of a decision table must always find a unique rule in any possible situation. Another way to state this is to say that all the rules in a table must be independent. It is incorrect for any two rules in the same table to have identical condition entries. When two rules are not unique, they are called dependent. Note that two rules may be dependent even though their condition entries are not identical if they contain immaterial or implicit entries. This was demonstrated in the discussion of table 3.6.

If two rules are dependent and their action entries are the same, they are called redundant, whereas they are called contradictory if their action entries are different. It is not incorrect for two different rules to have the same action entries. In some cases, two such rules may be combined into one. If two rules have identical entries for all conditions but one and have the same action entry then the two rules can be made into one by placing an immaterial entry at the condition that had the different values. Note that the different values in the two original rules should be a true and a false; if not, one or both of the rules probably contains an error.

Completeness. One benefit that can be derived from expressing logic in a limited entry decision table format is that it is possible to determine if the logic is complete. A decision table is complete if its decision tree contains no else rules. This is the same as saying that a decision table is complete when its condition entries contain all of the possible combinations of values for its conditions. Note that this test of completeness does not consider any logic contained in the conditions.

The recommended way to check the completeness of a decision table is to generate a decision tree, but it is not the only way. A classical way of checking the completeness of decision tables is to count the equivalent

simple rules [14]. A simple rule is one that contains only true and false entries. A decision table with n conditions will have 2^n unique simple rules. Most decision tables will contain entries other than true and false. The counting procedure is easily extended to those with immaterial entries. Defining a compound rule as one that contains an immaterial entry, a compound rule with r immaterial entries represents 2^r equivalent simple rules. A decision table with n conditions is complete if the sum of simple rules--both explicit and equivalent--is equal to 2^n and the rules are unique.

Consider table 3.12 (the condition entry from table 3.7). The last two rows are tabulations of the number of immaterial entries and of equivalent simple rules for each of the rules in the table. The total number of simple rules is 20, much less than $2^6 = 64$, so the decision tree should contain else rules, which it does, as shown in figure 3.6 in section 3.4. Each of the else rules in the figure can be considered a compound rule with immaterial entries for those conditions not included on their path. Thus, the first else rule does not test conditions five and six so it represents four equivalent simple rules. Likewise, the second else rule represents eight equivalent simple rules and the last one contains 32. The total number of simple rules shown in the tree is the sum 20 + 4 + 8 + 32 = 64, which is the proper total for a decision table with 6 conditions.

An instance where counting simple rules in a table with immaterial entries can lead to an error is when two or more of the compound rules contain the same simple rule. This error will not occur when using the decision tree approach because such compound rules are dependent and will always be identified as such. If the rule counting method is used to check completeness of tables with immaterial entries, care must be exercised to detect dependent rules.

Table 3.12 Counting simple rules

	1	2	3	4	5	6	
Condition 1	T	F	F	F	F	F	
Condition 2	T	T	F	.	.	.	
Condition 3	T	T	T	F	F	T	
Condition 4	T	T	T	T	T	T	
Condition 5	.	.	.	T	F	.	
Condition 6	.	F	F	.	.	T	
r	2	1	1	2	2	2	
2^r	4	2	2	4	4	4	=> $\Sigma 2^r = 20$

Implicit entries in a table make the counting of equivalent simple rules unreliable. The reason is that it is not predictable (with any ease) how many simple rules a rule with implicit entries may represent.

As previously stated, the recommended procedure for checking the completeness of a decision table is to use the decision tree to locate else rules. All of the else rules, that is, any rule not included in the original table, will be detected using the decision tree. The condition entries for an else rule can be found by tracing along the path from the else rule to the start of the tree, taking the condition entry from the sense of the branch. Any condition not encountered on the path will have an immaterial entry. Note that implicit entries can not be detected from the decision tree. Once all the else rules have been found, each should be examined to determine why it was not anticipated in the original table.

Generally speaking, decision tables for standards should be complete, because an else rule indicates an error situation. Some tables may be formulated using an else rule to lead to a specific action. For example, rules 5 through 10 in table 3.13 in the next section could be replaced with one else rule leading to action two. However, it is recommended that this approach not be used by the analyst until all of the rules have been examined. Once this is accomplished, the else rule may be a convenient shorthand.

One exception to this completeness-checking procedure can occur when tables have implicit entries. It is possible to generate an else rule in the decision tree which is opposite to the implicit entry in some stated rule. These else rules do not make the table incomplete.

<u>Style of Table.</u> Previously, it was pointed out that the manner of defining data items and writing actions has a bearing on the complexity of the decision tables produced. One example from a model building code [1] will be used to illustrate this. The provision of interest is included in section 1411.0 of the code and is shown in figure 3.3. This section includes provisions for sign materials, bottom clearance, maximum height, and support materials. For the purpose of this analysis, bottom clearance has been included in the provision for maximum height.

A decision table was written for checking the provision for the maximum height, with two possible actions (1) height acceptable and (2) height not acceptable. The decision table appears in table 3.13 and involved a significant amount of preparation. Note, among other things, that conditions 3 and 4 are mutually exclusive but not collectively exhaustive, and that bottom clearance has been made condition 1 in this table rather than a separate provision.

Table 3.13 is logically complete but complex. Introduction of a new data item called "Maximum allowable height" leads to a substantial simplification using two decision tables instead of one, as shown in table 3.14.

The revised set of tables involves fewer decisions and is less subject to misinterpretation.

Section 1411.0 Roof Signs

1411.1 Materials: All roof signs shall be constructed entirely of metal or other approved noncombustible materials except as provided in section 1409.5. Provision shall be made for electric ground of all metallic parts; and where combustible materials are permitted in letters or ther ornamental features, all wiring and tubing shall be kept free and insulated therefrom.

1411.2 Bottom Clearance: There shall be a clear space of not less than six (6) feet between the lowest part of the sign and the roof level except for necesssary structural supports.

1411.3 Closed Signs: A closed roof sign shall not be erected to a height greater than fifty (50) feet above fireproof and noncombustible buildings (types 1 and 2) nor more than thirty-five (35) feet above the roof of non-fireproof (type 3) buildings.

1411.4 Open Signs: An open roof sign shall not exceed a height of one hundred (100) feet above roof of buildings of fireproof and noncombustible construction, (type 1 and 2); and not more than sixty (60) feet above the roof of buildings of non-fireproof (type 3) construction.

1411.5 Combustible Supports: Within Fire Districts Nos. 1 and 2, no roof sign which exceeds forty (40) feet in height shall be supported on or braced to wooden beams or other combustible construction of a building or structure unless otherwise approved by the building official.

Figure 3.3 Sample provisions

Table 3.13 First approach to checking maximum height

		1	2	3	4	5	6	7	8	9	10
1	Clearance < 6′	T	T	T	T	T	T	T	T	T	F
2	Sign const. = closed	T	T	F	F	T	T	F	F	.	.
3	Bldg. type = 1 or 2	T	-	T	-	T	-	T	-	F	.
4	Bldg. type = 3	-	T	-	T	-	T	-	T	F	.
5	Height > 35′	.	F	.	.	-	T	+	+	.	.
6	Height > 50′	F	-	.	.	T	.	+	+	.	.
7	Height > 60′	-	-	.	F	.	.	+	T	.	.
8	Height > 100′	-	-	F	-	.	.	T	.	.	.
1	Height acceptable	X	X	X	X						
2	Height not acceptable					X	X	X	X	X	X

Table 3.14 Second approach to checking maximum height

		1	2	3	4	5	6
1	Clearance < 6′	F	T	T	T	T	T
2	Sign const. = closed	.	.	T	T	F	F
3	Bldg. type = 1 or 2	.	F	-	T	-	T
4	Bldg. type = 3	.	F	T	-	T	-
1	Max. height = 0′	X	X				
2	Max. height = 35′			X			
3	Max. height = 50′				X		
4	Max. height = 60′					X	
5	Max. height = 100′						X

Height ≤ max. height	T	F
Height acceptable	X	
Height not acceptable		X

623.31 Dimensions: Stairs shall be at least twenty-two (22) inches wide with risers not more and treads not less than eight (8) inches and landings at foot of stairs not less than forty (40) inches wide by thirty-six (36) inches long, located not more than eight (8) inches below the access window or door.

Figure 3.4 Sample provision

Combined Conditions. It was stated previously that conditions may be composed of compound logical statements, and that use of such conditions is frequently advantageous in that the number of rules is reduced. Another provision taken from a model building code [1] and shown in figure 3.4 illustrates this. It should be clear from the language of this provision that only one compound logical statement is required in the condition stub. The resulting decision table is shown in table 3.15.

3.3.2 Proper Usage

Many of the suggestions for proper use have been introduced in narrative form in section 3.3.1 and will be summarized here.

Table size. It is best to restrict tables to manageable size, of the order of 10 rules at most. Tables much larger than that tend to be difficult to formulate and analyze.

Completeness of stubs. The first step in analyzing a provision should be the complete listing of all possible conditions and actions, as illustrated in section 3.3.1. This discipline is most helpful in subsequent analysis; it is also an early indication that the table may be too large, and that the provision could fruitfully be subdivided into several smaller tables.

Table 3.15 Compound conditions

		1	2
1	Stair width ≥ 22" AND Riser ≤ 8" AND Tread ≥ 8" AND Landing width ≥ 40" AND Landing length ≥ 36" AND Landing below access 0≤x≤8"	T	F
1	Dimensions acceptable	X	
2	Dimensions not acceptable		X

Top-down development. As an alternative to the above recommendation, one may begin to analyze requirements in a top-down fashion by recognizing that a requirement may have only two actions: requirement satisfied or requirement violated. Attention can then focus on the conditions. Again, if too many conditions are involved, the requirement provision may be subdivided into one table for the requirement itself, and one or more subtables for the key ingredients.

Incremental development. Once the conditions and actions are identified, a good strategy to follow is first to identify only those condition entries that represent directly the statements in the original provision, leaving all other entries as immaterial. Then, interaction among rules and tests for uniqueness can be examined by generating a tree, and immaterial entries modified to implicit entries as needed on succeeding iterations.

Compound conditions. As illustrated in section 3.3.1, individual conditions occurring together may be combined into compound conditions using logical connectives of AND and OR.

Compound actions. The evaluation of both requirements and determinations frequently involves selecting the minimum or the maximum of several expressions. As illustrated by table 3.8, such "subsidiary" tests can be handled in the action stub by conditionals. However, as discussed in connection with that table, such conditionals are "buried" in the stub, and are not available for testing. Also, such "buried" provisions are not available for classification purposes: in the example shown, one cannot attach separate classifiers to the two expressions to indicate that one guards against failure by yielding while the other pertains to rupture.

Boolean vectors. Examples such as table 3.10 illustrate the point made in section 3.1.3 that many conditions involve testing a Boolean vector variable against one of its possible values.

Identification of ingredients. SASE at present does not analyze the contents of the condition and action stubs. Thus, it is the analyst's responsibility to ensure that all elements of the condition and action stubs other than constants and operators are defined data items, representing the ingredients of the datum generated by the decision table. Consistent with the top-down development sketched above, the analyst may develop the table first and then use it to ADD the INGREDIENTS of the DATUM represented by the table.

3.3.3 Representation

Each decision table is represented in SASE by a TABLE entity.

A table is referenced by the REFERENCE number of its corresponding data item (see section 3.1.3). To establish the cross-reference between the datum and the table, when the ENTER TABLE command is given, the attributes of the datum are automatically set as follows:

- SOURCE is set to DERIVED; and

- TYPE is set to TABLE

The attributes of a table entity are its CONDITIONS, ACTIONS and RULES, and COMMENT.

Since in SASE, actions can only produce alternative values for the data item represented by the table, it follows that each rule can have only one action entry. Thus, SASE uses a condensed form for the input of action entries. Table 3.16 repeats shows the action entry portion of table 3.5, each action corresponding to a different assignment of F_c. The action entry form used in SASE is shown in table 3.17.

SASE permits two modes for entering tables: by row (conditions followed by actions) or by columns (rules).

In the row-entry mode, conditions are entered in the following order:

- a sequential condition number starting with 1;
- an optional condition stub entered as a text string;
- the separation symbol "*";
- the condition entries, separated by blanks, each entry one of the symbols:

  T or Y for yes or true (the symbols are equivalent)
  F or N for no or false (the symbols are equivalent)
  \+ for implicit yes
  \- for implicit no
  . or I for immaterial (the symbols are equivalent)

The keyword CONDITIONS is given at the beginning of the first condition row and either CONDITIONS or the repetition symbol ";" is given at the beginning of each succeeding row. A dollar sign "$" at the end of a line signifies continuation.

SASE accepts the number of entries in the first condition row as the number of rules in the table, and expects all succeeding rows to have the same number of entries.

To complete the row-entry mode, actions are entered in the following order:

- a sequential action number starting with 1;
- an optional action stub entered as a text string;
- the separation symbol "*";
- a list of the rule (column) number(s) which result in this action, as shown in table 3.17, separated by commas.

Table 3.16 Standard form of rule entry

Rules

	1	2	3	4	5	6
Action 1	X					
2		X				
3			X	X		
4					X	
5						X

Table 3.17 Condensed form of action entry

Rules

	1	2	3	4	5	6
Actions	1	2	3	3	4	5

The key word ACTIONS is given at the beginning of the first action row, and either ACTIONS or the repetition symbol ";" for each succeeding row. A dollar sign "$" at the end of a line signifies continuation.

The keyword END completes the entry of the decision table.

In the column-entry mode, rules are entered in the following order:

- a sequential rule number starting with 1;
- the condition entries, as above;
- the separation symbol "*";
- an action number for the action corresponding to this rule.

The keyword RULES is given at the beginning of the first rule, and either RULES or the repetition symbol ";" for each succeeding column. A dollar sign "$" at the end of a line signifies continuation.

Again, the keyword END completes the entry of the decision table.

Note that condition and action stubs cannot be ENTERed in the RULES form of input; they must be ADDed subsequently.

SASE accepts the number of condition entries in the first rule as the number of conditions, and expects all succeeding columns to have the same number of condition entries. Similarly, SASE accepts the highest action number in any one rule column to be the number of actions.

Once a table has been ENTERed, stubs and condition and action entries may be ADDed, MODIFYed and DELETEd. Furthermore, additional conditions, actions, and rules may be ADDed sequentially to the existing ones. Finally, an ELSE rule may be ADDed to the existing rule.

The conditions, actions, and rules may also be arbitrarily RESEQUENCEd.

In its present version, SASE treats condition and action stubs as text, i.e., it performs no analysis of any kind. Subsequent versions of SASE may include additional processing capabilities, i.e., identification of ingredient data items from the stubs or direct generation of executable computer programs [17].

3.4 Decision trees

3.4.1 Definition

The logic contained in a decision table can be expressed as a decision tree, which is a network with one condition at each node. The branches from each node represent the possible condition entries and the termination of each path, or limb, is a rule. Figure 3.5 gives an example of a decision tree generated from a hypothetical decision table.

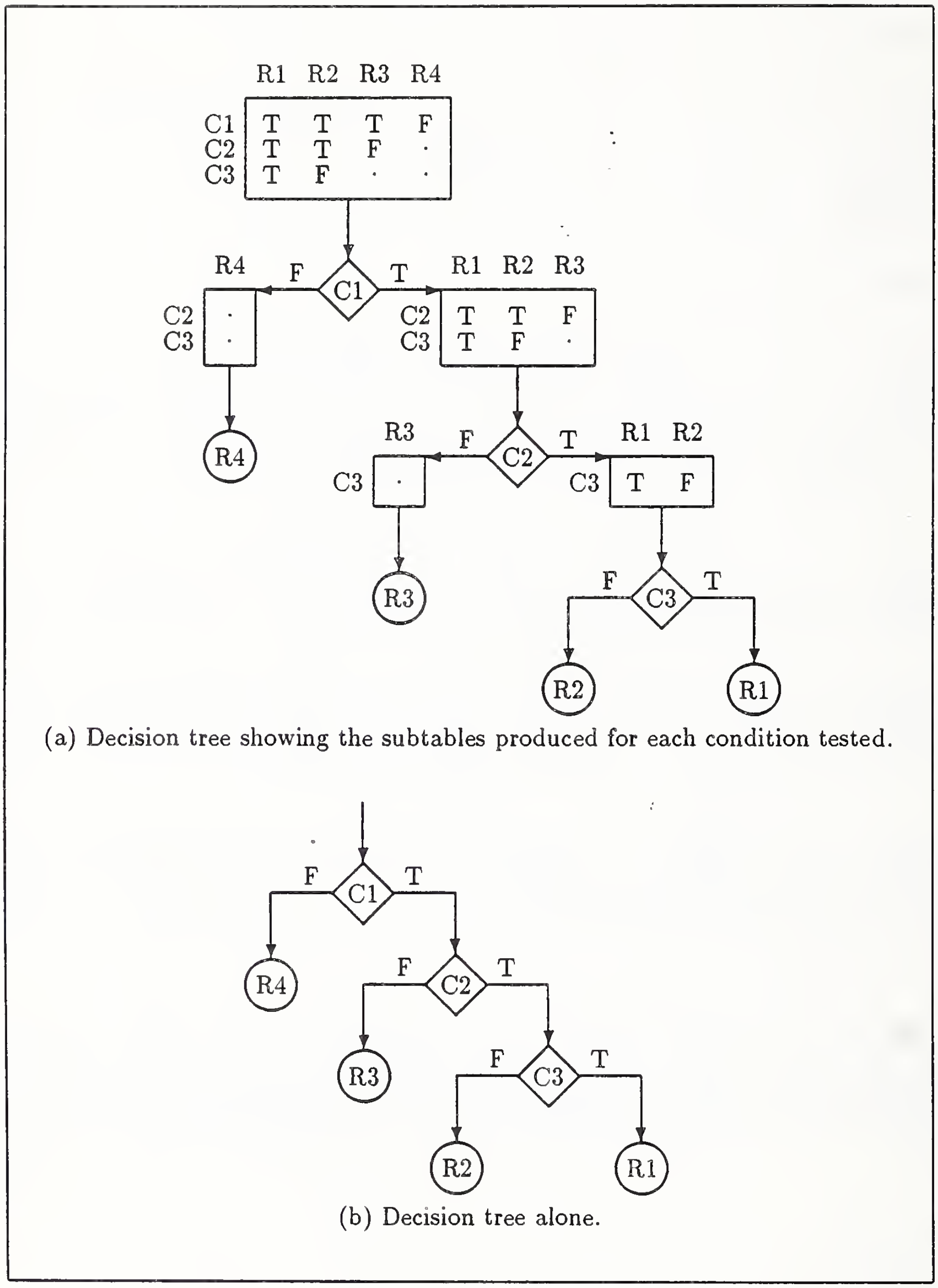

Figure 3.5 Decision tree generation from a hypothetical decision table.

The process of generating a decision tree from a decision table can be summarized by the following steps [20]:

1. Begin with the original table (the condition entry is all that is necessary).

2. Select a condition to test. Table 3.18 provides rules for condition selection that result in an efficient decision tree.

3. Produce two subtables. Each will contain the remaining conditions not yet tested. One will contain those rules for which the tested condition is true, the other those rules for which it is false. A rule with an immaterial entry will be in both new subtables.

4. If the new subtable contains at least one condition and more than one rule, go to step 2 and repeat the cycle; else, go to step 5.

5. There are four possibilities at this stage:

   - The subtable contains exactly one rule and no conditions except those with immaterial entries. The rule has been isolated, so the path is ended.

   - The subtable contains one rule and at least one condition with a true or false entry. Return to step 2 and continue.

Table 3.18 Rules for selecting a condition for testing

1	One condition has fewest immaterial entries	T	-	-	-
2	One of the conditions tied for fewest immaterial entries has fewest implicit entries	.	T	-	-
3	Quick rule desired	.	.	T	-
4	Delayed rule desired	.	.	-	T
1	Select condition with fewest immaterial entries	X			
2	Select condition with fewest implicit entries		X		
3	Select condition tied for fewest immaterial and fewest implicit entries that has greatest difference between number of true and false entries			X	
4	Select condition tied for fewest immaterial and fewest implicit entries that has least difference between number of true and false entries				X

- The subtable contains no rules. The rule isolated was not included in the original table. The union of all such rules is called the else rule.

- The subtable contains no remaining conditions, but does contain two or more rules. The rules are not independent; that is, they can be satisfied by the same set of condition entries. The remaining rules are either redundant or contradictory.

The expression of logic in a decision tree strongly resembles a conventional flow chart.

Note that more than one network can be generated from any decision table, depending on the order of selection of the conditions for testing, but that a unique set of condition entries will always isolate the same rule. Decision trees can be generated from extended entry tables also; however, the number of branches leaving each node depends on the number of unique entries for the condition. One of the advantages of a limited entry table is that the decision tree will always have two branches coming out of each condition node.

The decision tree derived from table 3.7 is shown in figure 3.6. There are three else rules identified: that is, rules that are not in the table. Examination of the entries for condition four in table 3.7 shows that the false entry is never used; this is pointed out in the decision tree by the existence of only an else rule on the false branch from condition four. The second footnote in the original provision pertains to that situation, but no specific disposition is made (a limitation on w/t of 60 does exist elsewhere in the specification.)

When implicit entries are encountered in the decomposition of a table into a decision tree, the same steps described above are followed. The implicit entries are treated somewhat differently than explicit or immaterial entries. First, it is efficient to avoid testing conditions with implicit entries, similar to the efficiency gained in the avoidance of immaterial entries. However, the avoiding of immaterial entries takes precedence over implicit entries. When new subtables are formed by separating the true rules and false rules for the condition being tested, the implicit entries are used like explicit entries to determine the subtable for a rule. For example, a rule with a "+" for the condition being tested is entered in the subtable of true rules, but not in the subtable of false rules. When a subtable contains only one rule, the implicit entries are treated as immaterial entries. That is, they need not be tested to verify the rule.

The decision tree generated from table 3.9 is shown in figure 3.7. Compare it to the decision tree shown in figure 3.6: it is much more compact since fewer conditions need be tested. In addition, two of the else rules that appear in figure 3.6 but represent impossible situations have disappeared in figure 3.7.

```
C4 + + + C1 + + + C2 + + + C3 + + + R1
 -        -        -        -
 -        -        -        - - - - ELSE
 -        -        -
 -        -        - - - - ELSE
 -        -
 -        - - - - C3 + + + C6 + + + R6
 -                 -        -
 -                 -        - - - - C2 + + + R2
 -                 -                 -
 -                 -                 - - - - R3
 -                 -
 -                 - - - - C5 + + + R4
 -                          -
 -                          -
 -                          - - - - R5
 -
 - - - - ELSE
```

Figure 3.6 Decision tree in SASE format generated from Table 3.7 ("+" denotes branch corresponding to true value of condition tested, "-" to false value).

```
C3 + + + C1 + + + R1
 -        -
 -        - - - - C6 + + + R6
 -                 -
 -                 - - - - C2 + + + R2
 -                          -
 -                          - - - - R3
 -
 - - - - C4 + + + C5 + + + R4
          -        -
          -        - - - - R5
          -
          - - - - ELSE
```

Figure 3.7 Decision tree in SASE format generated from table 3.9.

Implicit entries make a tremendous difference in the number of else rules encountered in the decision tree. Compare the two decision trees derived from tables 3.4 and 3.10, shown in figures 3.8a and 3.8b. The former has 15 else rules while the later has three. The else rules in figure 3.8b represent possible combinations of material strengths and electrode types that are not included in the decision table because nothing was said about them in the table in the original specification. The question arises from this analysis as to whether the electrodes listed with the various material strengths are the only ones permitted for use. This question can be resolved only by consultation with the experts who wrote the specification.

3.4.2 Proper Use

Generate early and often. While decision tables are convenient and compact representation of the logic of provisions, decision trees are the best tool for checking tables for uniqueness, completeness and, to a lesser degree, clarity. Therefore, a decision tree should be generated and analyzed as soon as a skeleton decision table is formed, and the tree re-generated and examined whenever the table is significantly modified.

Corrections. If the analysis reveals two or more redundant rules, the table should be carefully examined. Two redundant rules should differ by a true and false entry for one condition; if that is the case, the two can be combined into a single rule with an immaterial entry; if not, then one or both rules must be in error. If two contradictory rules are found, the action entry may be in error, or the logic may be at fault, probably because one or more immaterial entries are improperly used.

Use of ELSE. Most decision tables representing provisions of standards are highly incomplete, in that the number of actual rules is considerably less than the number of possible combinations of conditions. The ELSE qualifier should be used to generate the rules not defined in the table. Each ELSE rule should be carefully analyzed to determine whether it represents:

- a combination that is impossible because of related conditions;
- an omission from the original standard that must be rectified; or
- a combination that falls outside the scope of the standard.

3.4.3 Representation

In SASE, decision trees are generated by the GENERATE TREE command. A decision tree is referenced by the reference number of the decision table or, more precisely, of the datum derived by the decision tree.

The GENERATE TREE command has a number of optional qualifiers that control the processing.

ORDER specifies the sequence in which condition rows are selected for testing: INPUT specifies that conditions are to be tested in the original

```
         C1 + + + C2 + + + C3 + + + C4 + + + ELSE
          -        -        -        -
          -        -        -        - - - - C5 + + + ELSE
          -        -        -                 -
          -        -        -                 - - - - C6 + + + ELSE
          -        -        -                          -
          -        -        - - - - ELSE               - - - - R1
          -        -
          -        - - - - ELSE
          -
          - - - - C3 + + + C2 + + + C4 + + + ELSE
                   -        -        -
                   -        -        - - - - C5 + + + ELSE
                   -        -                 -
                   -        -                 - - - - C6 + + + ELSE
                   -        -                          -
                   -        - - - - ELSE               - - - - R2
                   -
  (a)              - - - - C2 + + + C4 + + + C5 + + + ELSE
                            -        -        -
                            -        -        - - - - C6 + + + ELSE
                            -        -                 -
                            -        -                 - - - - R3
                            -        -
                            -        - - - - ELSE
                            -
                            - - - - C4 + + + ELSE
                                     -
                                     - - - - C5 + + + C6 + + + ELSE
                                              -        -
C2 + + + C1 + + + C3 + + + R1                 -        - - - - R4
 -        -        -                          -
 -        -        - - - - ELSE               - - - - C6 + + + R5
 -        -                                            -
 -        - - - - C3 + + + R2                          - - - - ELSE
 -                 -
 -                 - - - - C4 + + + R3
 -                          -
 -                          - - - - ELSE
 -
 - - - - C5 + + + R4
          -
          - - - - C6 + + + R5
                   -
  (b)              - - - - ELSE
```

Figure 3.8 Comparision of decision trees in SASE format generated from (a) table 3.4 and (b) table 3.10.

input sequence, while QUICK or DELAY specify the test sequences discussed below.

The specific algorithm operates as follows:

- first priority: find the condition row with the minimum number of immaterial entries ("." or "I").

- second priority: find the condition row with the maximum number of explicit entries ("T", "Y", "N", or "F").

- third priority:

  - for the QUICK rule algorithm, find the condition with maximum difference between the number of true ("T" or "Y") and false ("F" or "N") entries.

  - for the DELAY rule algorithm, find the condition with minimum difference between the number of true ("T" or "Y") and false ("F" or "N") entries.

The ELSE qualifier causes all ELSE rules to be generated and added to the defined rules.

The SORT qualifier rearranges the tree and the corresponding table so that shorter branches of the tree are displayed before the longer branches.

The algorithm produces an error message if:

- any redundant rules are detected (i.e., rules are not unique and their action entries are the same); or

- any contradictory rules are detected (i.e., rules are not unique but their action entries are different).

When either of these errors occur, no tree is generated. The user must MODIFY the original decision table and re-execute the GENERATE TREE command.

3.5 Functions

3.5.1 Definition

Not all provisions depend upon conditions for their evaluation. A provision which does not require the evaluation of any conditions (i.e., leads to a "degenerate" decision table with only one rule and one action) is called a function.

Functions have been classified in [8] as

- definite functions;

- indefinite functions; and

- implied functions.

A definite function provides a specific, unambiguous means for deriving the value of a dependent data item. The most common means are formulae or tables.

An indefinite function specifies a set of ingredients for the evaluation of a derived data item, but does not specify precisely how the ingredients are to be used in the evaluation. An illustration is taken from section 4.2.2 of [18].

> "4.2.2 Period Determination
>
> The fundamental period of the building, T, (used) in formula 4-2 may be determined based on the properties of the seismic resisting system in the direction being analyzed and the use of established methods of mechanics assuming the base of the building to be fixed . . ."

In this instance the datum "Calculated fundamental period" is said to be an indefinite function of the following ingredients:

- Period calculated using established methods

- Properties of seismic resisting system in direction being analyzed

- Building assumed to be fixed at base

An implied function is used to denote instances in which the provision of a standard seems to indicate a precedence relation between data items, but the analyst must make some assumption as to what that relation is. Sometimes the assumption is so strongly implied that the ingredience relation can be treated just as was the indefinite function described previously. However, the implication may be weak or nonexistent. Such instances are called assumed functions. Two examples illustrate the typical characteristics of such provisions.

The first is a sentence from section 7.2.1 of [18]:

> "The strength of foundation components shall not be less than that required for forces acting without seismic forces."

It is assumed that the "forces acting without seismic forces" include all other forces that are included in [18]. Thus the data item, "Required strength without seismic load" is said to be an assumed function of the ingredients:

- Dead load effect

- Live load effect

- Snow load effect

The second example is from section 1.2 of [18]:

> "These provisions establish requirements for strengthening of existing buildings where alterations reducing the seismic force resistance are made ..."

Among the data items identified in the provision is: "Seismic force resistance before proposed activity." It is assumed that this resistance should be determined according to the provisions of the remaining chapters, however, no data items can be identified as specific ingredients.

3.5.2 Proper Use

Identification of ingredients. SASE at present does not perform any analysis of the body of functions. Therefore, it is entirely the analyst's responsibility to identify the ingredients of the datum generated by the function.

Clarification of function type. The analyst should ask the drafting committee to clarify the type of function used, and attempt to have the committee eliminate as many of the indefinite and implied functions as possible. In many instances, it is not appropriate to have a definite function appear in the standard itself (e.g., the ingredient "period calculated with the use of established methods of mechanics" in the first example in section 3.5.1); in such cases, the commentary to the standard may be an appropriate medium to describe or reference the applicable function.

Expansion to decision table. Many determinations that appear to be functions on first reading may turn out to be decision tables when footnotes, exceptions, etc. are also included. In such cases, the FUNCTION must be DELETEd and a new TABLE ENTERed.

3.5.3 Representation

Each function is represented in SASE by a function entity or record.

A function is referenced by the REFERENCE number of its corresponding data item (see section 3.1.3). As with decision tables, when the ENTER FUNCTION REFERENCE in command is given, the attributes of the datum are set as follows:

- SOURCE is set to DERIVED

- TYPE is set to FUNCTION

The only attribute of a FUNCTION entity is its BODY, entered as a text string.

3.6 Networks

3.6.1 Definition

General. A network can be defined as a set of points connected by lines. The points are called nodes and the lines are called branches. A branch may only be connected to two nodes, one at each end, and branches may only be connected at nodes, although they may cross over one another at points without impairing the generality of the definition [3].

The information network used to represent the precedence relations of the information contained in a standard is formed by assigning one data item to each node. These nodes may be: numerical quantities such as material strength; qualitative values such as the type of occupancy of a building; or Boolean values such as the status of a requirement (satisfied or unsatisfied). In order to provide a more concise representation of the relations among data items, each detailed decision table or function is abstracted into a subnetwork, or subtree, consisting of:

1. a node representing the derived item generated by the table or function;

2. nodes representing all the data items occurring in the table or function, i.e., the ingredients; and

3. directed branches from each ingredient to the node representing the derived data item.

The nodes in set (2) are called the (direct) ingredients of node (1); conversely, node (1) is called a (direct) dependent of all nodes in set (2).

Each decision table establishes the value for one data item, so each decision table is uniquely associated with a node in the network. Some nodes represent items that have their value established by a function; in such cases the function is associated with the node as if it were a decision table.

There will be data items that have no procedure for evaluation contained within the standard. The nodes for these items are called input nodes because their value must be supplied by sources of information outside the standard.

Construction of the Network. The global network can be assembled by interconnecting the subtrees representing the individual provisions. Provisions leading to an illustrative network are shown in figure 3.9, which is a simplification of the provisions for the design of simply reinforced beams taken from [2].

The network is shown in figure 3.10.

In this network, we can trace out the global dependence of a node, that is, all data items affected by the datum. By following the branches in the

Decision table for tension reinforcement requirement

	1	E
$p \le 0.75\ p_b$	Y	
$p \ge 200/f_y$	Y	
$M \le M_u$	Y	
TROK = satisfied	X	
TROK = violated		X

Decision table for k_1 factor

	1	2
$f'_c \le 4000$	Y	N
$k_1 = 0.85$	X	
$k_1 = 0.85 - 0.00005(f_c - 4000)$		X

Supporting functions

$$p = \frac{A_s}{bd}$$

$$\emptyset = 0.90$$

$$p_b = 0.85\ k_i \frac{f'_c}{f_y} \frac{87000}{87000 + f_y}$$

$$q = p \frac{f_y}{f'_c}$$

$$M_u = \emptyset\ bd^2\ f'_c\ q(1 - 0.59q)$$

Figure 3.9 Simplified provisions for the design of simply reinforced concrete beams.

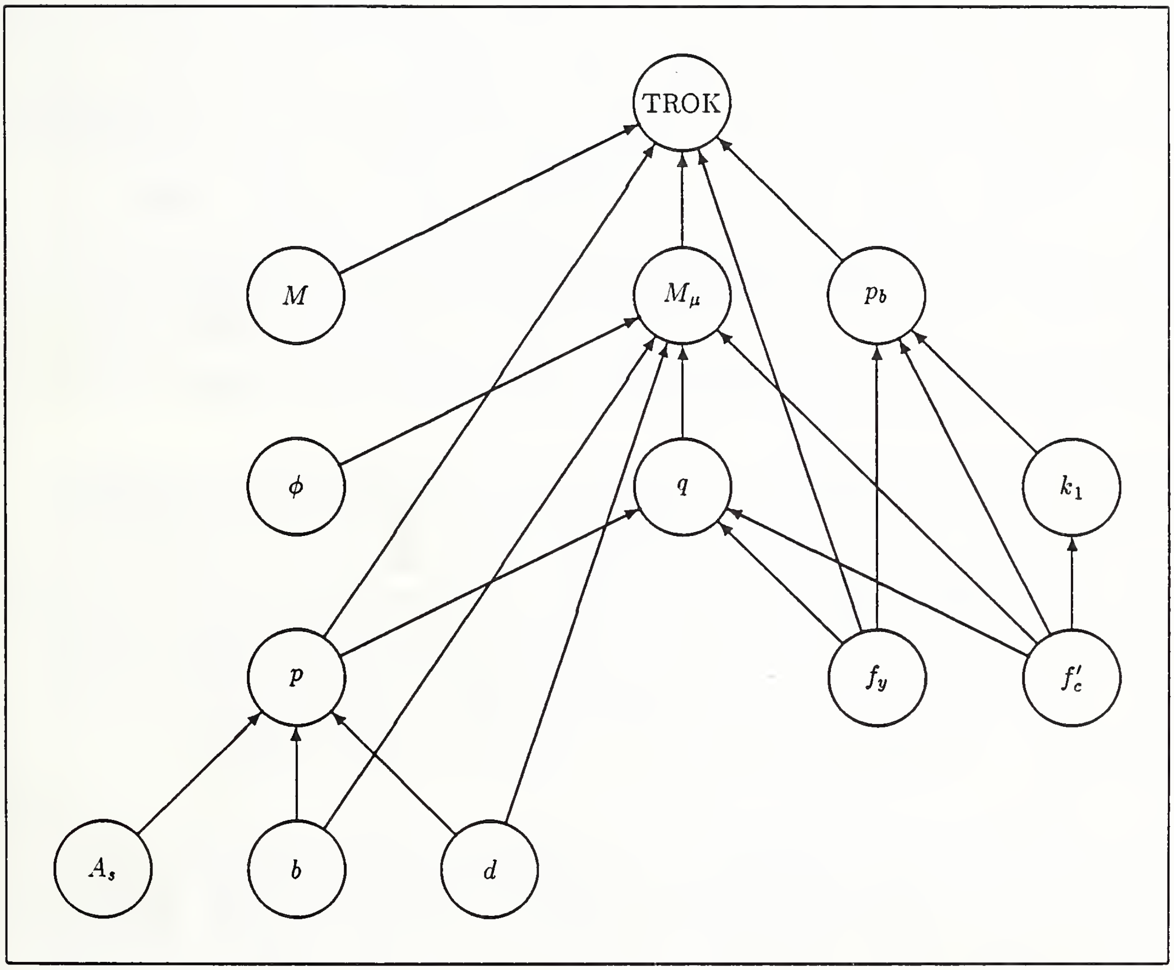

Figure 3.10 Information network for simplified provisions for the design of simply reinforced concrete beams.

reverse direction, we can trace out the global ingredience of a node, that is, all data items needed to evaluate the datum. We can also classify the nodes into:

- input data items, that is, nodes without ingredients;
- derived data items, that is, nodes with one or more ingredients; and
- output data items, that is, nodes with no dependents.

The input nodes will have no ingredients. All of the nodes that have ingredients are called derived nodes. The information network does not show how they are derived; it shows only the data items that may be necessary in order to derive the value. Some of the nodes (at least one) will have no dependents; they are called terminal or output nodes of the network. The output nodes represent the requirements included within the standard. The concept of using the requirement as the output node is rather arbitrary, since one final node could be defined as "standard satisfied". However, this would be an ambiguous, cumulative requirement. It is advantageous to truncate the network at some convenient definition of requirements in order to provide freedom in the use of the organizational network, as is discussed in chapter 4.

<u>Characteristics of the Network.</u> One of the characteristics of the information network that can be used to advantage in the formulation and expression of standards is its concise representation of all the information contained in the standard. The simple process of defining a consistent set of items of information can lead to the identification of extraneous items. When an existing standard is being analyzed or restructured, a preliminary list of the items of information would be one of the first steps in the analysis. Ingredients do not become apparent until the examination of the detailed logic involving each data item is begun. The study of the detailed logic is described in section 3.3 on decision table analysis.

Once the network is constructed from the list of nodes and their ingredients, it is possible to discern global ingredience and dependence properties of the hierarchy of information. The global ingredience of a particular node is the portion of the overall network located on branches pointing towards the node: it is a subnetwork that begins at the node in question, then goes to each of its ingredients, which are followed in turn by each of their ingredients in a recursive manner until all of the branches end at input nodes. The direction of traversing this network is counter to the direction of the branches. The global dependence is constructed in a similar manner, except dependents are used: the final nodes are the output nodes, and the direction of traversing is in the direction of the branches as defined originally. In summary, the global ingredience shows all of the nodes that may have a direct or indirect effect on the node in question. The global dependence shows all of the nodes that may be affected by the node in question.

Computations on the Information Network. A number of useful computations can be performed on a network. The network can be viewed as a critical-path-method (CPM) diagram with all branches having a length of one unit. Labelling the terminal (output) node 0, the labels of all nodes are determined as:

$$L^o_k = \max\ (L^o_j + 1)$$

where j ranges over the set of direct dependents D_k of node k. The corresponding labels are shown on figure 3.11, and represent the highest or latest level from output of each node.

Alternatively, the input nodes are labelled 0, and the labels of all nodes determined as:

$$L^i_k = \max\ (L^i_j + 1)$$

where j ranges over the set of direct ingredients I_k of node k. The corresponding labels are shown on figure 3.12 and represent the highest level from input of each node.

Finally, to complete the CPM analogy, the float of every node is calculated as:

$$F_k = L_{max} - (L^i_k + L^o_k)$$

where

L_{max} = maximum label in network

= longest path from input to output

The various quantities for the sample network are tabulated in table 3.19 below.

The input level, output level, and float are three properties of the nodes in a network that are of considerable use in the expression of a standard, as discussed below.

Connectedness. Information networks frequently will have more than one node at the output level. It is entirely possible that the information network for a standard will consist of more than one completely separate network, although this possibility seems improbable. Such cases do not alter the generality of what has been described. The definition of what constitutes an output mode is somewhat arbitrary, as discussed previously.

Acyclic Networks. Information networks will generally have many closed loops or cycles, although none of them may be traversed completely without going counter to the direction of at least one branch. Such a network is called acyclic. If it were possible to traverse a complete loop in the direction of the branches, it would mean that a node might require assign-

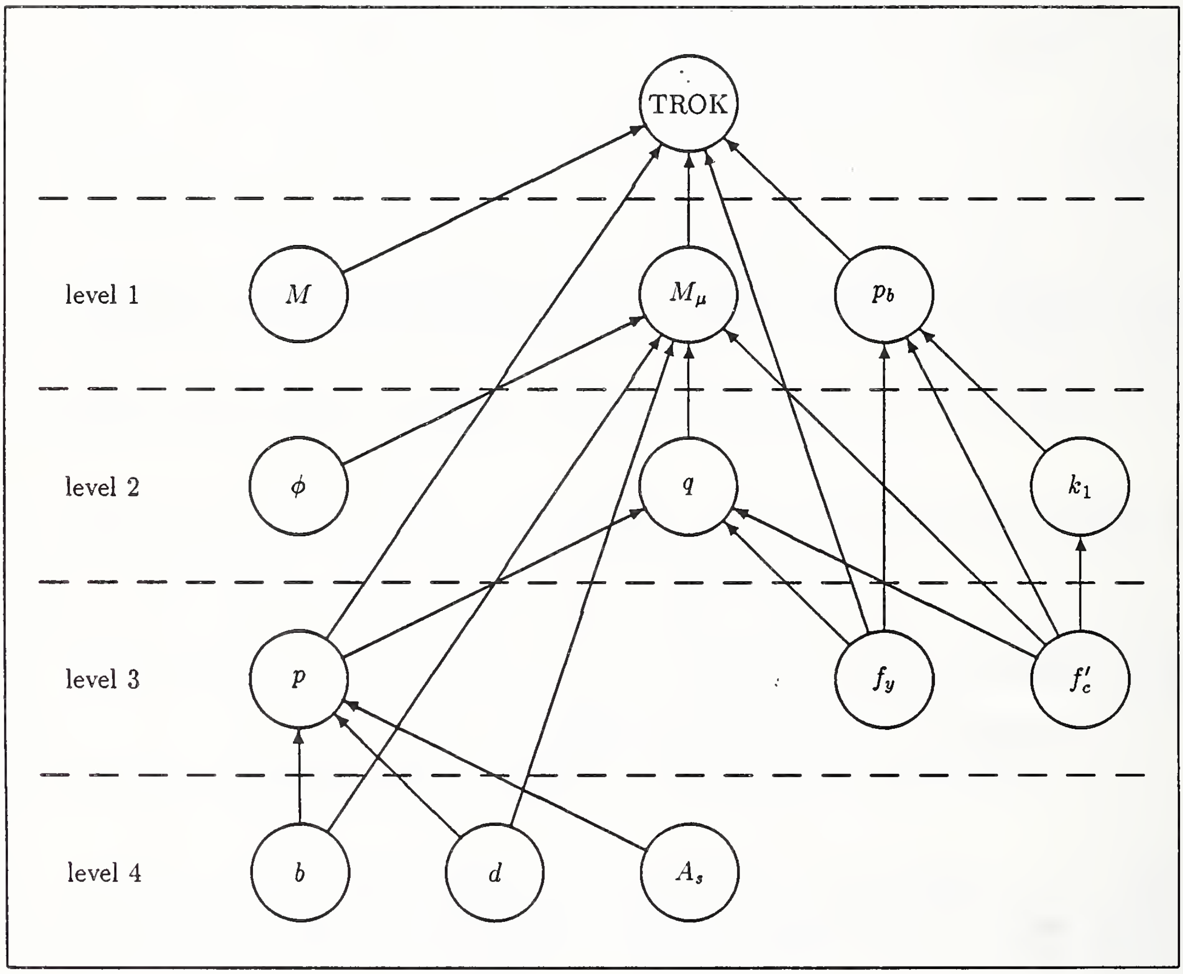

Figure 3.11 Information network ordered by levels from output data item.

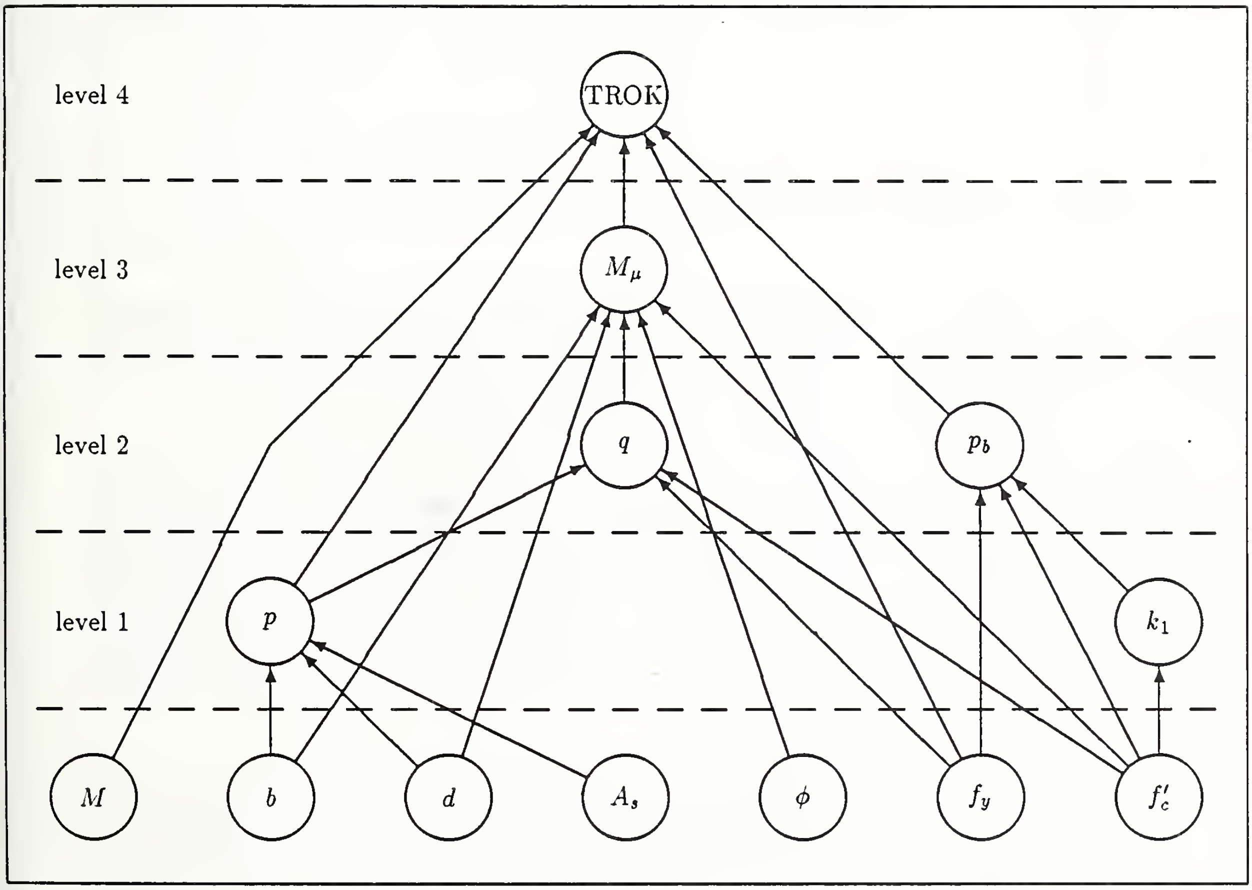

Figure 3.12 Information network ordered by levels from input data items.

Table 3.19 Levels and floats in example network

Node	Level from Output	Level from Input	Float
TROK	0	4	0
M	1	0	3
M_u	1	3	0
P_b	1	2	1
q	2	2	0
O	2	0	2
k_1	2	1	1
p	3	1	0
f_y	3	0	1
f'_c	3	0	1
b	4	0	0
d	4	0	0
A_s	4	0	0

ment of its value before it could be evaluated. While iterative calculation is used in many analyses, it is not appropriate in standards. When such a situation is encountered, it will be necessary to define two nodes as the initial and final values of a datum to break the loop.

Use in Formulation. Most of the uses of the information network in aiding the formulation of a standard are qualitative. One exception is the check that the network be acyclic, which can be detected explicitly in the construction of the network. Other explicit checks are that the network must have at least one output node and one input node. Disconnected portions of the network should be examined critically. When the disconnected portion consists of one node, an error in formulation is revealed. The node either has some ingredients that were left out, is an overlooked ingredient of some other node, or is not used at all.

The information network also allows the explicit determination of the global ingredience and global dependence of a node as described above. When a change in the definition (decision table) of a node is contemplated, the dependent network allows the effects of that change to be traced through the specification. Likewise the ingredience network allows any subset of the specification to be checked for consistency.

One qualitative check is that provisions dealing with parallel situations should be located at approximately the same level from output. The comparison of output levels is based on the concept that provisions described by a nearly identical set of arguments (i.e., classifiers) should have nearly identical global dependence networks.

Another qualitative check is on the similarity of ingredients for various nodes. Particularly when reformulation of an existing standard is being pursued, it may be possible to combine several similar provisions taken

from different portions of the standard into one new provision, thus clarifying the intent of the provision.

Use in Expression. The information network is of use in composing the textual expression of a standard by providing a guide to the ordering of data items required for the definition of a set of related provisions and in the recognition of cross references. The overall organization of the text (ordering of sets of provisions) is somewhat independent of the information network and is discussed in the chapter on outlining.

Two schemes may be defined for the ordering of the data items used in the written expression of a set of provisions represented by an information network: conditional and direct [12, 13].

In the conditional or top-down strategy, we list the top node first, followed by its direct ingredients, that is, those at level 1 from output. Each of these, in turn, is listed with its direct ingredients, etc. The skeletal structure of the text for the sample network shown in figure 3.10 may read as follows:

> Tension reinforcement shall satisfy the following . . .
>
> M_u is evaluated as follows . . .
>
> q is evaluated as follows . . .
>
> p is evaluated as follows . . .
>
> p_b is evaluated as follows . . .
>
> k_1 is evaluated as follows . . .

(the input data items are not shown).

Comparison of the skeletal structure with figure 3.10 will show that the structure represents a particular path through the graph information network. The order in which the paths are traversed is immaterial, and will depend on the analyst's preference. What is important is that:

- every complete outline represents a spanning tree (that is, it contains every node) of the network, rooted at the terminal node; and
- branches of the network not included in the outline may be represented as cross-references to other nodes.

In the direct or bottom-up strategy, we list the input nodes first, followed by their direct dependents, that is, those at level 1 from input. Each of these, in turn, is listed with its direct dependents, etc. The skeletal structure may read as follows:

> Given b, d, and A_s' compute p as follows . . .

Given p, fy and f_c' compute q . . .

Compute k_1 . . .

Compute M_u . . .

Compute p_b . . .

Evaluate whether tension reinforcement requirement is satisfied.

Again, the writer has the option of ordering the nodes in one level, but the two properties discussed for the conditional strategy still hold: the outline is a spanning tree, and all cross-references point to nodes previous defined.

Direct ordering will lead to a boring style of writing when the global ingredience of a provision is several levels deep, because the reader is forced to read the definition of all the possible ingredients before the provision is located. Conditional ordering allows the user familiar with the standard to cease reading the text of a set of provisions when he has read the first statement, if he is already aware of the definition of items close to input, or if he is only scanning the major requirements.

The global ingredience network alone is not sufficient for organization of the textual expression needed to define a set of provisions. One difficulty is that it does not indicate which of the several nodes at a given precedence level should be used first. The problem cannot be completely separated from the logic expressed in the decision tables. The float and output level may be of some aid. They are simple numerical indicators of the depth of precedence, or numbers of intermediate steps between the input and output node and the node in question. Ingredients that have the largest float or level will generally have the smallest global ingredience networks and thus will be easier to define. In some cases, it will be most convenient to order the ingredients that are defined in the simplest manner first; however, no consistent rule concerning this has been developed.

Another benefit that the information network offers for formulation and expression of standards is the explicit recognition of cross-references. Frequently, input parameters and derived data are used in the evaluation of more than one provision. Proper cross-referencing depends on the recognition of these reuses of the same data items. This becomes more important in larger standards because cross-referenced nodes will sometimes have a large global ingredience of their own. Cross-referencing is necessary to prevent presentation of duplicative material and possible confusion.

3.6.2 Proper Use

<u>Proceed from small to big.</u> It is best to generate and analyze smaller networks corresponding to individual chapters before combining the data items into larger networks for several chapters.

Corrections for loops. If the analysis reveals the presence of loops, these must be eliminated. Loops may result from:

- "circular" definitions, where a data item is in its own global ingredience network. Such data items must be redefined and the ingredients modified accordingly;

- iterative calculations, involving a trial and error procedure. Such procedures are not appropriate for a standard; if absolutely needed, two data items must be defined, e.g., one for the assumed and one for the computed value of the datum in question, where the assumed value is treated as an input data item;

- overly strict interpretation of some cumulative requirements (see section 3.3) or indefinite functions (see section 3.5). Once identified, these items must be reinterpreteted.

Detached subnetworks. Detached subnetworks should be examined with care. It will frequently happen that subnetworks corresponding to individual chapters will have several detached subnetworks, to be "connected" later through cross-references between chapters. This is a valid occurrence of detached subnetworks. By contrast, an undesirable situation is one where the detached subnetwork is within the scope of the chapter, but there is no "logical" way to interconnect it with the remainder of the chapter through compound requirements.

Choice of SORT. The SORT qualifier determines the ordering of nodes in a subsequent DISPLAY of the network (see the next section). No firm rules can be given on the choice of the SORT qualifier. Generally SMALL SMALL should be tried first: it will put shorter paths ahead of longer ones.

3.6.3 Representation

In SASE, a network is generated by the GENERATE NETWORK command. In the present implementation of SASE, there can be only one network for each VERSION of a standard. Therefore, the network is not given an explicit reference number. The user must specify the CHAPTERs of the version to be included in the network.

In SASE the network can be DISPLAYed as a spanning tree, that is, a tree containing all of the nodes in the network. Each branch of the tree corresponds to a path through the network. The SORT qualifier controls the order in which nodes appear in the tree. If the SORT qualifier is used, either FLOAT or LEVEL may be specified as the primary key; the other will be taken as the secondary key. The first SMALL or LARGE qualifier indicates sorting on the primary key in descending or ascending order, respectively. The second SMALL or LARGE qualifier indicates the sorting order for the secondary key.

SASE produces an error message if a loop is detected, and prints out the list of nodes (data item reference numbers) constituting the loop. The user must modify the INGREDIENTs of one or more data items to break the

loop before the network can be generated. SASE does not generate any error messages if disconnected subnetworks are encountered.

The DISPLAY NETWORK command provides two basic options for displaying the network:

- If INGREDIENCE or DEPENDENCE is specified, a spanning tree is displayed, indented by levels; either the ENTIRE network or a subnetwork rooted at a specified node may be requested.

- If DATALIST is specified, a tabular display of data items is produced, including the LEVEL and FLOAT attributes of each data item.

4. ORGANIZING THE INFORMATION OF A STANDARD

The organization of a standard deals with both the scope (the range of subject matter) and the arrangement (the grouping and ordering) of the provisions it contains. An effective organizational system assists the writers of a standard in defining its scope and assists the user of a standard in quickly and reliably finding the relevant provisions. This chapter presents the SASE techniques for dealing with the organization of a standard. Major sections are: Classifiers, Hierarchy, Scopelist, Index, Organization, and Outline.

4.1 Classifiers

4.1.1 Definition

Classifiers are words that concisely define the scope of a provision. All provisions that are requirements should be classified for the purpose of generating organizations and outlines; frequently, key provisions that are determinations also are classified, at least for indexing purposes.

As discussed in section 3.2, a requirement contains at least two basic components. The subject of the requirement may be a physical entity, process or participant, collectively these are referred to as THING in the following. The predicate of the requirement defines the REQUIRED QUALITY of the subject. Classifiers serve to identify, relate, and organize the subjects and the predicates.

Faceted Classification System. The SASE methodology for classification of provisions of standards is based on the faceted classification system developed for library science. The essence of a faceted classification can be reduced to three features:

1. The classification consists of several more or less independent areas, called fields and facets. A field can be thought of as a subject area (such as architecture) and a facet can be thought of as a way to classify within a particular field (a classification of architectural objects might have facets for material, historical period, form, etc.).

2. Each facet is structured hierarchically and may have several levels.

3. Rules are provided for combining terms from different facets for the classification of an entire standard.

Within a facet, the classifiers should be logically structured, that is, the classifiers should be:

1. mutually exclusive at every level of the hierarchy to guarantee that each provision is uniquely described by one set of classifiers only,

2. collectively exhaustive at every level to ensure complete coverage, and

3. strict subdivisions of the parent classifier in the hierarchy.

Development of a Classification System. There are five important principles that govern the development of a faceted classification system for the provisions of a standard:

1. There must be at least two independent fields: one for THING and one for REQUIRED QUALITY of the provisions (see section 3.2). Relevant classification of requirements requires this as a minimum. There also may be independent fields for determinations. The fact that the fields are independent facilitates the construction of a classification and allows great freedom in constructing alternative arrangements.

2. Each facet must be a strictly logical tree. That is, each succeeding level must be a direct subdivision of the parent and the logical principles of mutual exclusion and collective exhaustion must be satisfied at each level. This logical rigor is not typical of faceted classification systems, but it is required of the classification system of a standard in order to satisfy two of the objectives of organization: uniqueness and completeness (see section 4.6).

3. A field may have any number of facets, and each facet, except the root facet, must be a logical subdivision of some other classifier in the field. In order to provide an outline that is unique, complete, and graded (see section 4.6), it must be possible to combine the facets in at least one way to produce a single logical tree for the entire field. Thus the potential connections between facets must be stated explicitly. A corollary of this principle along with the first principle suggests that the same facet not be used in more than one field.

4. The maximum number of siblings (classifiers having the same parent classifier) at any level should not exceed a reasonable estimate of the span of immediate memory of the user, of the order of five to ten.

5. The facets should promote an even division of the scope of the standard.

The third principle merits additional discussion. One use of the classification system is to build an outline, which should follow the logical principles as much as possible. Thus, it is desirable to avoid the possibility of a tree containing siblings that are not mutually exclusive and it is necessary to avoid any closed meshes. Non-exclusive siblings is the more substantive concern because closed meshes rarely arise in practice. The first concern is satisfied by allowing only one facet to be appended to any one classifier.

Consider the example taken from [18] shown in figure 4.1.

Two of the three facets in figure 4.1a apply to the classifier "Building Part," which is a terminal classifier of another facet (not shown). The third facet applies only to the combination of the classifiers "Seismic resisting" and "Component." As is frequently the situation, it is necessary to be able to subdivide a single classifier (Building Part) into more than one facet. To accomplish this logically, the subdivisions are applied successively rather than concurrently. Thus, the second facet is applied to the terminal classifiers of the first facet, as shown in the left column of figure 4.1b. The right column of figure 4.1b shows a variation that maintains logical rigor but it does so by dividing the facet "Function of Building Part" into subfacets. This subdivision of facets is quite useful in constructing outlines, and will be discussed further.

- Function of building part
    - Structural
        - Seismic resisting
        - Non-seismic resisting
        - Foundation
    - Nonstructural

- Scale of building part
    - System
    - Component
    - Material

- Type of seismic resisting component
    - Frame
    - Shear panel

a) Three logical facets, shown in indented outline format

- (Function of building part)
    - Structural
        - Seismic resisting
            - System
            - Component
                - Frame
                - Shear panel
            - Material
        - Non-seismic resisting
            - System
            - Component
            - Material
        - Foundation
    - Nonstructural

- (Function of building part)
    - Structural
        - System
            - Seismic resisting
            - Non-seismic resisting
            - Foundation
        - Component
            - Seismic resisting
                - Frame
                - Shear panel
            - Non-seismic resisting
            - Foundation
        - Material
    - Nonstructural

b) Two possible ways of combining the three facets into a tree

Figure 4.1 Sample combinations of facets of subject classifiers

The example shows several other interesting features. Note that the name of the facet disappears when it is appended to another classifier. In this sense, the name of a facet is transparent. Also note that facets need not be appended at all possible locations--"Scale of building part" is not appended to "Foundation" in the left column of figure 4.1b, and the second level subfacet of "Function of building part" is not appended to "Material" in the right column of figure 4.1b. In addition, a single facet may require the context of presence (or absence) of several other classifiers to be relevant--"Type of seismic resisting component" is attached to only those branches in figure 4.1b containing the classifiers "seismic resisting" and "components." Techniques for combining facets are discussed in more detail in the description of outlining methods in section 4.6.

The division of the facet "Function of building part" shown in figure 4.1b illustrates that the fundamental unit of the classification is a single set of sibling classifiers connected to their parent classifier. This unit is the smallest unit that preserves the logical principles; hereafter it is termed a <u>nuclear tree</u>. For purposes of combining classifiers into an outline, a facet may be divided into its constituent nuclear trees. Thus the logical structure of a classification system may be summarized as follows:

1. A nuclear tree is the smallest logical unit.

2. A facet consists of one or more nuclear trees and is the largest logical unit. It may be subdivided into smaller logical units at any time.

3. A field consists of one or more facets and does not necessarily maintain logical rigor. Each field is considered to be an independent classification.

It is important that any deviation from the above logical principles be soundly based, and that the classification still give an unambiguous indication of the applicability of a particular requirement to a particular classifier. The logical principles can be relaxed when classifying for the purpose of indexing, but it is more convenient to treat this subject in the principles for classing provisions.

In addition to following the principles just presented, care must be taken to provide relevant and progressive ordering of the classification.

<u>Classing Provisions.</u> There are five principles pertinent to the association of classifiers and provisions, that is, to the assignment of arguments to data items. These principles are:

1. Each requirement must be classed according to THING and to REQUIRED QUALITY.

2. No provision may be classed by more than one classifier from any one facet.

3. Each classifier associated with a provision must be the most detailed that includes the scope of the provision.

4. All terminal classifiers must be associated with at least one provision.

5. It is permissible to establish a priority among the classifiers associated with a provision.

The first principle assures relevance based on the model of the underlying structure of requirements. No comparable model or principle exists for determinations.

The second and third principles are simply corollaries of the logical principles. It frequently is useful to violate both of them when classing for the purposes of indexing. Consider a provision that applies to both the "Seismic resisting" and "Foundation" parts of the "Structure", but not to the "Non-seismic resisting" parts (refer to the first facet in figure 4.1a). Outlining has the function of finding a single best location in a linear list for a provision. Thus, according to the logical principles, the provision must be classed as "Structure". Indexing has the function of directing a user to a provision from any relevant starting point, thus the provision is most appropriately classed "Seismic resisting" and "Foundation." It is fairly simple to account for different ways of classing the same provision and to call on the appropriate classification for a given purpose.

The fourth principle prevents useless detail in the classification system.

The fifth principle is useful in outlining. In the light of the basic structure of classification, it appears that such a priority will be of the most use when applied to classifiers from different facets in the same field. Thus a provision classed as "Structure", "System", and "Seismic resisting" from the facets in figure 4.1a (with the first facet subdivided as previously described) might be more appropriately placed in one or the other outlines of figure 4.1b based on the priority given to "System" and "Seismic resisting."

<u>Basic Categories.</u> The establishment of a set of basic categories gives a firm starting point for the development of a classification for a particular standard. In this section, categories appropriate for use in design standards for buildings are proposed, with some discussion of their importance, application, and interrelationships. It is expected that the same or similar categories would be appropriate for standards that pertain to other subjects or that are broader in scope than building design. The objective in presenting these categories is to provide an aid for the development of a relevant and meaningful classification. They should be reviewed for any specific application. The indiscriminate application of these or any other basic categories is unwise.

The structure defined in section 3.2.1 for a requirement provides the basis for deriving basic categories. There must be at least two major independent fields, one for the THING (subject) and one for the REQUIRED QUALITY (predicate). Both of these are too general for the present purpose; their major constituents, which may be fields or facets, are the real interest.

Figure 4.2 summarizes the basic categories proposed for classifying requirements. The lower portion of the figure consists of categories that are useful in particular situations; thus they are termed facets.

The figure is not a logical classification itself, and there may well be other usable facets not included. A brief discussion of each category with selected examples follows.

<u>Categories of THINGS.</u> Three principal categories of THINGS are shown in figure 4.2. They are: Physical Entities, Human Entities, and Processes. (By definition, Human Entities are distinct from all other Physical Entities.) Some potential for ambiguity exists between Human Entity and Process for some provisions and between Physical Entity and Process for other provisions. These ambiguities are usually resolvable by considering the most relevant REQUIRED QUALITY.

A most important factor in the classification of THINGS is the whole-to-part relationship, shown as a "multi-purpose" facet in figure 4.2. A common characteristic of Physical Entity classification is the large number of levels that are typically related in the fashion of "system-subsystem-component-constituent." Similarly, Processes can be divided into stages. Great detail in the whole-to-part naming of Physical Entities is common in prescriptive standards; it is somewhat antithetical to the concept of a performance standard. Where innovation is desired, too much whole-to-part naming can restrict freedom. Where easy judgment of compliance is desired, a classification strongly tied to the most common implementations is desirable. As the facets of figure 4.2 are reviewed, the whole-to-part relationship should be kept in mind.

There is considerable richness in the way the Physical Entities are named and classified. Following are examples to help define the facets in figure 4.2.

- Function: the division of stairs into required exits and supplemental exits; the division of a structural system into seismic resisting and non-seismic resisting subsystems.

- Material: the division of structural components into wood, steel, reinforced concrete, masonry, etc.

- Dimensions: the division of buildings into one-story and multi-story.

- Exposure (Circumstances): the division of components into those in contact with corrosive fluids, those in contact with soil, etc.

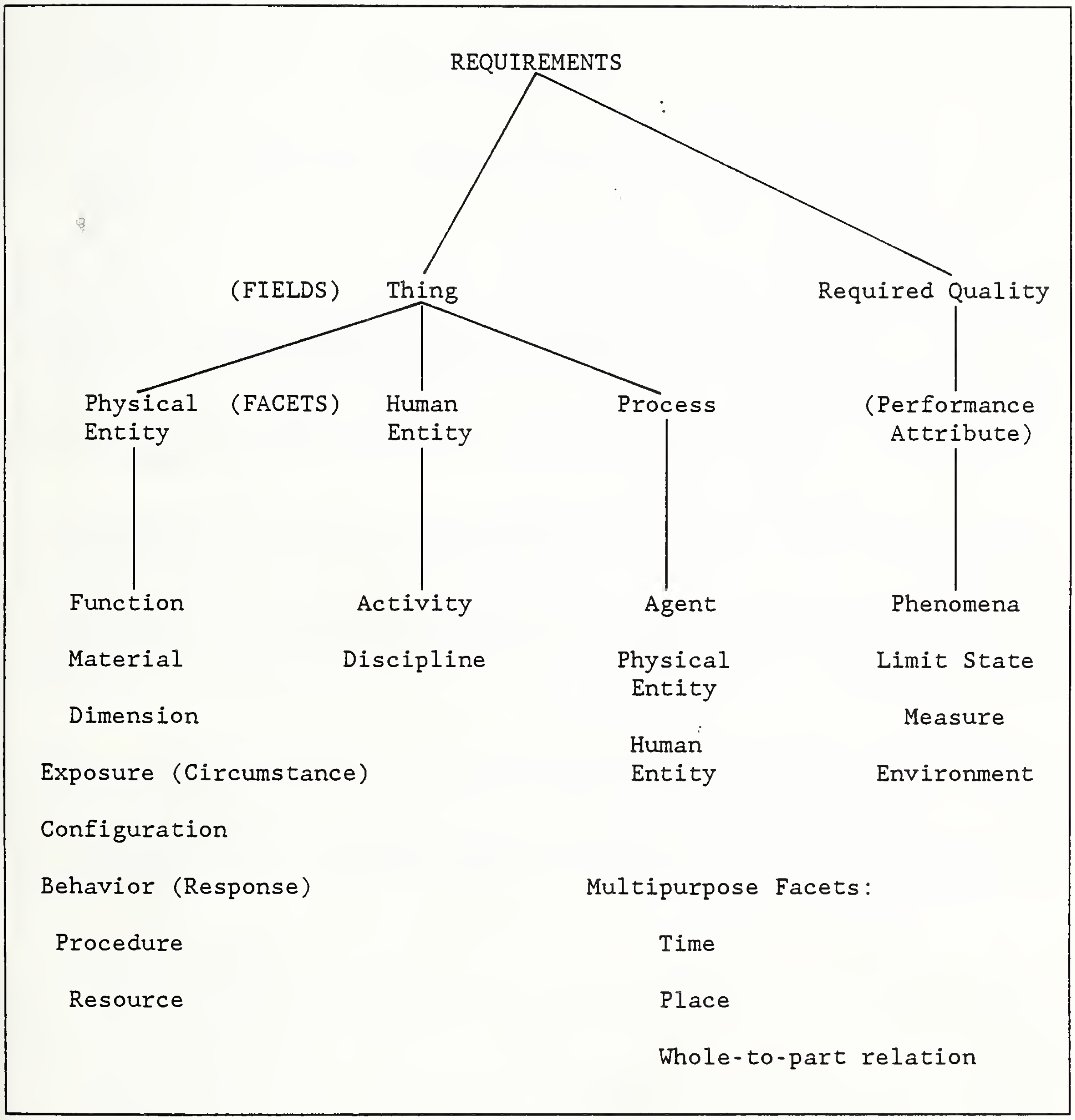

Figure 4.2 Basic categories for requirements.

- Configuration: the division of stairs into straight, spiral, etc.

- Behavior: the division of materials into brittle and ductile.

- Procedure: the division of concrete components into those cast-in-place and those precast.

- Resource: the division of energy sources into coal, oil, nuclear, solar, etc.

- Time: the division of buildings into existing and proposed.

- Place: the division of components by location on the top story, below grade, etc.

Examples of the facets for Human Entity are:

- Activity: the division into users of buildings and agents of the building process; the division of users into occupants, maintenance crews, neighbors, etc.

- Discipline: the division of designers into architects, structural engineers, mechanical engineers, etc.

- Time: the division of licensed designers by the date of registration.

- Place: the division of licensed professional designers by state of registration.

Similar examples for facets of Process are:

- Agent: the division into natural processes, such as corrosion, and human operations, such as welding.

- Physical Entity: the division of pile driving by types of piles, for example: open steel section, closed steel section, timber, and precast concrete piles.

- Human Entity: the division of quality assurance activities into those carried out by the designer, the regulator, the contractor, etc.

- Time: the division of structural design into conceptual design, analysis, proportioning, detailing, etc.

- Place: the division of welding into shop welding and field welding, or downhand and overhead welding, etc.

Some useful facets may be a combination of some of the above. For example, in standards for the structural design of buildings a class of "stress states" (axial stress, flexural stress, shear stress, etc.) is very useful

for grouping components. The class can be thought of as Function, Circumstance, or Behavior, or some combination of them.

Categories of REQUIRED QUALITIES. The classification of REQUIRED QUALITIES does not show the richness of the classification of THINGS, but this is not an indication of simplicity. The first problem with the categories shown for REQUIRED QUALITY in figure 4.2 is that the principal category, Performance Attribute, is not explicitly stated in some standards, particularly in prescriptive ones. Another factor that contributes to the relative difficulty of developing a classification of REQUIRED QUALITIES is that the whole-to-part relation is rarely applicable, making the logical structure entirely dependent on the characteristics of the REQUIRED QUALITIES.

In spite of the problems, the classification of REQUIRED QUALITIES is worthwhile for two reasons. It is necessary to allow full and relevant classification of requirements, without which the access function of the organizational system would be severely hampered. It also allows a completely independent arrangement of a standard that concentrates on the objective rather than the subject, which is quite desirable for some individuals and some uses. Thus the categories of figure 4.2 are presented with the knowledge that difficulties may be encountered in the classification of REQUIRED QUALITIES.

A useful subdivision of the performance hierarchy is through the use of Limit States as classifiers of performance criteria. In the context of structural engineering, a Limit State has been defined as an event that may cause the loss of a performance attribute either by its occurrence or by its amplitude. Examples of limit states and their related performance attributes are "collapse of a building" (safety), "vibration of a floor" (comfort), and "cracking of a water tank" (function).

Measure is shown in figure 4.2 as a reminder that not all requirements can be classified through the performance hierarchy, and that even for those that can there exists a more basic facet for the REQUIRED QUALITY. In this sense, Measure is all-encompassing from the most fundamental qualities, such as existence, through the more remote or accidental qualities like "Circumstances."

4.1.2 Proper Usage

Many of the suggestions for proper usage have been introduced in narrative form in section 4.1.1, and will be summarized here essentially in the order in which a classification system is developed.

Basic Categories. The first and most critical step in developing a classification system is to define the basic categories or fields describing the scope of a standard. Figure 4.2 may be used as a guide, but modifications or extensions of that model may be in order for a specific standard.

Things and Required Qualities. In the analysis of an existing standard, it is usually easier first to construct the classification system for the THINGs covered, and then concentrate on their REQUIRED QUALITIES. By

contrast, in synthesizing a new standard, it is advisable first to identify the REQUIRED QUALITIES sought, and only then enumerate the THINGs which are to possess those qualities.

Fields and Facets. The distinction between fields covering large heterogeneous areas of subject matter and facets covering specific, homogeneous sub-areas is often problematical. An evolutionary approach is to start with many facets in a field and then examine them to see whether they could be logically combined into fewer, larger facets.

Logical Structure of Facets. Care must be exercised that the classifiers within a facet satisfy the three rules of logical structure given in section 4.1.1.

Classing Provisions. The true test of the classification system lies in the actual classing of provisions, i.e., the assignment of ARGUMENTS to DATUMs. The ease with which the five principles given in section 4.1.1 can be followed quickly will determine the usefulness and appropriateness of the classification system.

Interaction with data items. Of the five principles given in section 4.1.1, the most troublesome in practice is the second, namely, that no provision may be classed by more than one classifier from any facet. Potential violation of this principle may mean that the classification is too detailed, e.g., the classification distinguishes between "walls" and "diaphragms" whereas the provisions deal with walls and diaphragms. However, violation may also occur because the provisions themselves are too inclusive, i.e., they are multiple or cumulative requirements, as defined in section 3.2.1. In such cases, proper classification requires that the data items be redefined (see section 3.2.2).

4.1.3 Representation

Each classifier is represented in the SASE program by a classifier entity. The attributes describing a classifier are discussed below.

REFERENCE NUMBER The reference number is a numeric key for identifying the classifier. The reference number must be unique within a version. A convenient identification scheme is to use a five-digit reference number, the first two digits referring to the facet and the last three digits sequentially assigned within the facet in increments of ten, thereby providing space for new classifiers to be inserted later.

NAME Any short, mnemonically meaningful alphabetic designation may be given to the classifier.

TITLE Any descriptive title, entered as a text string, may be given to the classifier; its most common use is in the preparation of organizations, outlines, and indexes.

TYPE This attribute defines the way the classifier is to be used in organizations and outlines. Its possible values are:

- ACTUAL, meaning that the classifier will be displayed, or

- TRANSPARENT, meaning that the classifier will not be displayed in the outline.

PARENT A classifier may have a single parent or multiple foster parents. If a parent is entered, identified by its classifier reference number, the classifier belongs to the same facet as its parent, and is a direct subdivision of the parent classifier.

FOSTER The reference numbers of foster parents are entered only for classifiers that are roots of facets. These classifiers will be introduced in the organization as if the referenced foster parent(s) were true parent(s). The introduction of a classifier having more than one FOSTER parent may be made conditional on a specified CONTEXT with respect to classifiers PRESENT or ABSENT in the hierarchy above the classifier.

COMMENT Any descriptive information or comment, entered as a text string, may be attached to the classifier.

4.2 Hierarchy

4.2.1 Definition

A hierarchy is a tree of classifiers. The tree of a facet is formed by assigning one classifier to each node and forming a branch from each node to its parent. The tree of a field is formed as follows:

- the tree of the root facet of the field is formed;

- the trees of the remaining facets of the field are attached by branchs to the foster parents of the root nodes of the facets;

- if a facet has more than one foster parent, copies of the tree of the facet are attached by branchs to each of its foster parents satisfying the specified context.

The assembly of the hierarchy tree is readily done by SASE. The resulting tree can be examined for the desired properties of the classification scheme. As an illustration of the use of hierarchies to examine a classification scheme, figure 4.3 presents the Physical Entity field for a classification [9] for seismic provisions for buildings. The field has 21 facets. A recent reorganization [10] of the same classification produced the Physical Entity field shown in figure 4.4. The field now has eight facets, themselves arranged roughly in a system-component hierarchical order.

*Building
- Whole Building
- Part of Building

*Seismic Performance
- Category A
- Category B
- Category C
- Category D

*Seismic Hazard Exposure
- Group III
- Groups I and II (Not Used)

*Existence of Building
- Proposed (New)
- Existing

*Material Nature of Bldg Part
- Material Generic
- Material Specific

*Scale of Building Part
- System
- Component
- Material

*Function of Building Part
- Structural
  - Seismic Resisting
  - Non-Seismic Resisting
  - Foundation
- Non-Structural
  - Architectural
  - Mechanical/Electrical

*Structural Components
- Connection
- Member (Not Used)

(continued)

Figure 4.3 Physical Entity field from a classification [11] for seismic provisions for buildings showing 21 facets (* denotes the root of a facet).

```
*Materials of Construction
   Wood
   Steel
   Reinforced Concrete
   Masonry
*Type of Seismic Resisting Component
   Frame
     Moment Frame (Unbraced)
       Ordinary Moment Frame
       Special Moment Frame
     Braced Frame
   Shear Panel
     Shear Wall
     Diaphragm
*Frame Components
   Beam
   Column
   Joint
*Part of Shear Panel
   Boundary Member
   Web (not used)
*Part of Foundation
   Soil
   Foundation Structure
     Pile
     Non-Pile (not used)
*Non-Structural Components
   Equipment
   Anchorage
*Wood Design Method
   Conventional
   Engineered

(continued)
```

Figure 4.3 Physical Entity field from a classification for seismic provisions for buildings (continued).

*Part of Wood Shear Panel
    Framing (Wood)
    Sheathing
        Plywood
        Diagonal Board
        Other Sheathing Material
*Reinforced Concrete constituents
    Concrete
    Reinforcement (Concrete)
        Lateral Reinforcement
        Longitudinal Reinforcement
*Concrete Pile Construction
    Cast-in-Place
        Cased
        Uncased
    Precast
        Prestressed
        Non-prestressed (Not Used)
*Masonry Constituents
    Masonry Unit, Mortor, Grout
    Reinforcement (Masonry)
*Masonry Construction
    Unreinforced
    Stacked Bond
    Hollow Unit Masonry
*Type of Member Stress
    Axial Stress
    Flexural Stress
    Shear Stress
    Torsion Stress

Figure 4.3 Physical Entity field from a classification for seismic provisions for buildings (concluded).

```
*Building Type
   Proposed (New)
   Existing
*Building Function
   Seismic Performance Category
     Category A
     Category B
     Categories C and D
       Category C
       Category D
   Seismic Hazard Group
     Group 1
     Group 2
     Group 3
*System Type
   Structural
   Non-Structural
     Architectural
     Mechanical/Electrical
   Foundation
*System Function
   Seismic Resisting
     Frame
       Moment Frame (Unbraced)
       Braced Frame
     Wall
       Shear Wall
       Bearing Wall
       Screen Wall
     Diaphragm
     Horizontal Truss
   Non-Seismic Resisting
*Material
   Soil
   Wood
     Plywood
   Steel
   Concrete
     Unreinforced Concrete
     Reinforced Concrete
     Precast Concrete
     Cast-in-Place Concrete
(continued)
```

Figure 4.4 Physical Entity field from an alternative classification [12] for seismic provisions for buildings showing eight facets (* denotes the root of a facet).

*Material (continued)
- Masonry
  - Masonry Units, Mortar, Grout
  - Unreinforced Masonry
  - Reinforced Masonry
  - Stacked Bond Masonry
  - Hollow Unit Masonry
- Undifferentiated Material

*Element Type
- Beam
- Column
- Beam-Column
- Boundary Member
- Pile
  - Uncased Pile
  - Cased Pile
- Equipment
- Collector Member
- Tie Member
- Undifferentiated Element Type

*Part of Element or System
- Reinforcement
  - Lateral Reinforcement
  - Longitudinal Reinforcement
  - Reinforcement Splice
  - Reinforcement Anchorage
- Joint
- Member Anchorage
- Opening
- Sheathing and Diagonal Board
- Undifferentiated Part

*Element Function (stress)
- Axial Stress
- Flexural Stress
- Shear Stress
- Torsional Stress
- Undifferentiated Element Function

Figure 4.4 Physical Entity field from an alternative classification for seismic provisions (concluded).

4.2.2 Proper Usage

Proceed from small to big. It is best to generate and examine smaller hierarchies corresponding to individual facets before combining classifiers into larger fields.

Generate early and often. Hierarchies should be generated and examined as soon as a few classifiers have been identified, and regenerated whenever a significant number of classifiers is added or their relations modified.

Correct for loops. If the analysis reveals the presence of loops, these must be eliminated by redefining parent or foster parent relations among classifiers. Unlike loops in networks (see section 3.6), loops among classifiers arise infrequently, and are more likely caused by data entry errors than by logical flaws in the definition of classifier hierarchies.

4.2.3 Representation

In SASE, a hierarchy is generated by the GENERATE HIERARCHY command. Since all classifiers are identified with a VERSION of a standard, the hierarchy does not have an explicit reference number. If the FACET qualifier is used, separate facet hierarchies will be generated using the PARENT attributes only, starting from the root nodes of each facet (root nodes of facets have no PARENT). If the ALL qualifier is used, the facets will be combined into FIELDS, by connecting root nodes of facets through their FOSTER parent(s). The hierarchy will start from the root node(s) of field(s) (root nodes of fields have neither PARENT nor FOSTER parent). The inclusion in a particular field of a facet root node having more than one FOSTER parent is conditional on the CONTEXT specified for each FOSTER parent (see section 4.1.3).

SASE produces error messages if:

- a loop is detected (i.e., the hierarchy is not a strict tree), in which case a list of the nodes (classifier reference numbers) that form the loop is printed;

- a GENERATE HIERARCHY ALL is requested, but one or more facet root nodes are not linked up through FOSTER parents.

In either case, the user must MODIFY the PARENT or FOSTER parent of one or more classifiers before the hierarchy can be generated.

The DISPLAY HIERARCHY command provides a number of options for displaying a hierarchy:

- the display can show ALL nodes or only ROOTs or FIELDs or FACETs,

- the display can include the hierarchy of the entire VERSION or only a selected FIELD or FACET, and

- the display can be in STRUCTURE (indented) or LIST (tabular) form.

4.3 Scopelist

4.3.1 Definition

The scopelist is the basic cross-reference between classifiers and data items. The scopelist is generated by appending to each classifier the list of all data items having that classifier as one of its arguments. Thus, each datum will appear under each of the classifiers in its argument list. A scopelist for the fire escape example was shown in table 2.10. An example in SASE format is given in Appendix A.

4.3.2 Proper Usage

Proceed from small to big. It is best to generate and examine smaller scopelists before generating larger ones. As soon as the hierarchy of a facet appears satisfactory, it is advisable to generate a scopelist for that facet. Examination of the data items under each classifier will help in "calibrating" the classification scheme, namely, in deciding whether the classifiers appropriately identify and group related provisions. It may be advisable to perform this analysis on data items from individual chapters before performing it on the entire version. Conversely, particularly in synthesis, if the scopelist of some classifier(s) contains isolated data items from several chapters, regrouping those data items into more closely related chapters and redefining the classification scheme may both be appropriate.

Balance. The scopelist should be carefully reviewed for classifiers with an excessively large number of data items (the COUNT option is useful as a preliminary screening tool). Such large "clusters" warrant a review of both the classification scheme (to see whether one or more classifiers should be further subdivided) and the data items (to see whether requirements of the multiple or cumulative type should be subdivided).

4.3.3 Representation

In SASE, a scopelist is generated by the GENERATE SCOPELIST command. There can be only one SCOPELIST for each VERSION of a standard. Therefore, the scopelist does not have an explicit reference number. The user must specify the CHAPTERs to be included in the scopelist. A hierarchy must have been previously generated.

The DISPLAY SCOPELIST command provides a number of options for displaying a scopelist:

- all the options on choice and formats of classifiers discussed in section 4.2.3;

- the choice of all data items or only REQUIREMENTs or DETERMINATIONs (COUNT gives just the number of data items rather than a listing);

- the choice of all classifiers or only those used for OUTLINing or INDEXing.

4.4 Index

4.4.1 Definition

An index is a list of classifiers with a list of references to provisions associated with each classifier that provides access to the provisions. The simplest form is an alphabetical arrangement of the classifiers in a single level, with a cluster of references to the provisions associated with each classifier given below (hereafter called a "simple index"). Figure 4.5 is an example of such an index; it is a portion of the index produced for [18]. Each reference in a cluster consists of three parts: the datum number, the descriptive title of the datum, and the section or chapter number of the original text containing the provision. The datum number alone might suffice for access in some instances, but the descriptive title is particularly helpful in a simple index. It would be possible to include the page number. Note that the most common index for a book is a single level list of headings with a cluster of page numbers for each heading.

A characteristic defect of simple indexes is that many headings reference clusters containing too many provisions for efficient use. An index with multiple levels of headings, such as in figure 4.6a, aids the user by subdividing the clusters of references to provisions into more intelligible groups.

Indexing principles can be formulated for indexes with multiple levels of headings and for indexes with several classifiers for each heading (see figure 4.6 for examples of both). The former type is quite useful for large indexes. The latter type introduces more power and possibly more relevance, but also causes additional problems of length. It does not seem worth the added cost when the provision reference in the index contains the datum description, because the description and a heading containing most or all of the arguments of the provision are frequently very similar.

It is useful to include both requirements and determinations in the index. Even though all terminal, or highest level, data items correspond to requirements, use of the standard frequently requires access to non-terminal provisions for many purposes. This is particularly true for determinations that evaluate important characteristic quantities. The outline system primarily, but not wholly, provides access to the requirements, and the information network system primarily provides access to determinations through the ordering of the global ingredience of requirements. The index is essentially a backup access system and must provide access for both types of provisions.

As described in section 4.1.1, the logical principles for classing a provision may be violated for the purpose of indexing. Generally speaking, the arguments of a provision for outlining will be fewer in number than those for indexing. A common example would be a requirement with compound THINGS or REQUIRED QUALITIES. Such a provision must be related to a general classifier for unique placement in an outline, but for reliable access through

ALPHABETICAL INDEX	REFERENCE LOCATION
ACCESS/EGRESS: BLOCKED	
1472 GROUP III ACCESS REQUIREMENT	1.4.2(E)
ALTERATION	
1380 ALTERATION AND REPAIR REQUIREMENT	1.3.2
ANALYSIS	
3105 STRUCTURAL ANALYSIS REQUIREMENT	3.1
3381 CATEGORY C AND D INTERACTION REQUIREMENT	3.3.4(B)
4001 EQUIVALENT LATERAL FORCE ANALYSIS REQUIREMENT	CHAPTER 4
5001 MODAL ANALYSIS REQUIREMENT	CHAPTER 5
5210 MODELING REQUIREMENT	5.2
5310 MODES REQUIREMENT	5.3
5410 PERIOD AND MODE SHAPE ANALYSIS REQUIREMENT	5.4
6001 SOIL STRUCTURE INTERACTION ANALYSIS REQUIREMENT	CHAPTER 6
ANALYTICAL EVALUATION	
13226 ANALYTICAL EVALUATION PROCEDURES REQUIREMENT	13.2.2
13228 ANALYSIS METHOD REQUIREMENT	13.2.2
13230 DETAILS OF ANALYTICAL EVALUATION REPORT REQ	13.2.2
13246 RESULTS OF ANALYTICAL EVALUATION	13.2.2
13248 GOVERNING EARTHQUAKE CAPACITY RATIO	13.2.2
13262 ALLOWABLE EARTHQUAKE CAPACITY RATIO	13.2.2
ANCHORAGE	
8165 ARCH/MECH/ELEC ATTACHMENT REQUIREMENT	8.1.2
8240 EXTERIOR WALL PANEL ATTACHMENT REQUIREMENT	8.2.3
8315 AMPLIFICATION FACTOR FOR ATTACHMENT OF M/E COMP	8.3.2(A)
8321 TYPE OF RESILIENT MOUNTING SYSTEM	8.2.3, 2.1
8345 MECH/ELEC ATTACHMENT DESIGN REQUIREMENT	8.3.3
8369 M/E ATTACHMENT CERTIFICATION (TESTING) REQUIRED	8.3.4
ARCHITECTURAL	
8100 ARCH/MECH/ELEC PROVISIONS APPLICABLE	8.1
8105 ARCH/MECH/ELEC PERFORMANCE LEVEL	8.1, 8.1.3
8106 PERFORMANCE LEVEL FROM TABLES-B	TBL 8-B
8190 PERFORMANCE CHARACTERISTIC FACTOR	8.1.3, TBL 8-A
8200 ARCHITECTURAL DESIGN REQUIREMENT	8.2.1-5
8215 SEISMIC FORCE FOR ARCHITECTURAL COMPONENTS	8.2.3
8220 SEISMIC COEFFICIENT FOR ARCHITECTURAL COMP	8.2.3
8240 EXTERIOR WALL PANEL ATTACHMENT REQUIREMENT	8.2.3

Figure 4.5 Example of a simple index

```
CATEGORY A
   3620 CATEGORY A DESIGN AND DETAILING REQUIREMENT
   9300 CATEGORY A WOOD REQUIREMENT
  11300 CATEGORY A CONCRETE REQUIREMENT
  11310 CATEGORY A CONCRETE FRAMING REQUIREMENT
  11340 CATEGORY A CONCRETE ANCHOR BOLT REQUIREMENT
CATEGORY B
  BEAM
    11602 ORDINARY CONCRETE FLEXURAL MEMBER REQUIREMENT
    11604 ORDINARY CONCRETE FLEXURAL MEMBER REINFORCEMENT REQUIREMENT
    11618 ORDINARY CONCRETE FLEXURAL MEMBER MOMENT RESISTANCE REQ
    11628 ORDINARY CONCRETE FLEXURAL MEMBER REINFORCEMENT ANCHORAGE REQ
    11640 ORDINARY CONCRETE FLEXURAL MEMBER WEB REINFORCEMENT REQ
  CASED
     7476 CATEGORY B CASED CONCRETE PILE REQUIREMENT
  COLUMN
    11662 ORDINARY CONCRETE BEAM COLUMN LATERAL REINFORCEMENT REQ
  COMPONENT
    CASED
       7476 CATEGORY B CASED CONCRETE PILE REQUIREMENT
    CONCRETE
       7452 CATEGORY B UNCASED CONCRETE PILE REQUIREMENT
       7476 CATEGORY B CASED CONCRETE PILE REQUIREMENT
       7490 CATEGORY B CONCRETE FILLED STEEL PIPE PILE REQUIREMENT
       7492 CATEGORY B PRECAST CONCRETE PILE REQUIREMENT
       7494 CATEGORY B PRESTRESSED CONCRETE PILE REQUIREMENT
    DETAILED DESIGN
       3630 CATEGORY B DESIGN AND DETAILING REQUIREMENT
       3640 CATEGORY B OPENINGS REQUIREMENT
```

a) Multiple level headings

```
   CATEGORY B  CONCRETE ORDINARY MOMENT FRAME
     11600 CATEGORY B CONCRETE ORDINARY MOMENT FRAME REQUIREMENT
     11602 ORDINARY CONCRETE FLEXURAL MEMBER REQUIREMENT
     11604 ORDINARY CONCRETE FLEXURAL MEMBER REINFORCEMENT REQUIREMENT
     11618 ORDINARY CONCRETE FLEXURAL MEMBER MOMENT RESISTANCE REQ
     11628 ORDINARY CONCRETE FLEXURAL MEMB. REINFORCEMENT ANCHORAGE REQ
     11640 ORDINARY CONCRETE FLEXURAL MEMBER WEB REINFORCEMENT REQ
   CATEGORY B  CONCRETE PILE REINFORCEMENT
      7452 CATEGORY B UNCASED CONCRETE PILE REQUIREMENT
      7476 CATEGORY B CASED CONCRETE PILE REQUIREMENT
      7490 CATEGORY B CONCRETE FILLED STEEL PIPE PILE REQUIREMENT
      7492 CATEGORY B PRECAST CONCRETE PILE REQUIREMENT
      7494 CATEGORY B PRESTRESSED CONCRETE PILE REQUIREMENT
```

b) Multiple classifier headings

Figure 4.6 Examples of advanced indexes

an index it would be better if the provision were related to specific classifiers for each of the compounded THINGS or REQUIRED QUALITIES. Another common example is the addition of more general classifiers for indexing when the arguments are of a very narrow scope.

In some instances, classifiers are associated with provisions purely for the purpose of arrangement in outlining. For example, requirements for the performance of a structure might be classed according to the stages of the design process in which the requirement normally would be satisfied. Such classification is relevant in outlining, but possibly can be misleading in indexing, if the same classifiers are used (1) to indicate the THING or REQUIRED QUALITY of some requirements and (2) for arranging some other requirements pertaining to other THINGS or REQUIRED QUALITIES. The user of the index has no sure way of distinguishing between these two purposes, and he might assume that the heading (classifier) is related to the THING for each associated provision. For the purpose of indexing, a provision should be deleted from the scope list of a classifier when that classifier is associated with the provision only for purposes of arrangement in outlining.

Logical classing is not necessary for indexing because the structure of an index depends primarily on the relation of a classifier and a provision. The relations between classifiers are much less important. The index does not have a unique location for each provision reference; it generally will have several, even if the classing is strictly logical. The index benefits from relaxation of logical rigor when it can make the product more natural, and when the relaxation can do no harm.

An alphabetical ordering of the headings in an index is meaningful and well accepted. The other choice for indexing is to order the headings by their positions in the trees of classifiers. The alphabetical order appears preferable because it is common to so many indexes and because doing so relieves one from making decisions about the ordering of fields and facets for use as an index. Adopting the alphabetical order adds importance to the ordering of words in multi-word headings. Thus classifiers containing more than one word ideally should have the most relevant word placed first.

The production of an alphabetical index of the simple type on a computer is quite elementary, once the classification, the provision references, and the arguments for each provision have been stored. Two preliminary steps are the transposition of the argument lists to determine the provisions associated with each classifier (i.e., generation of the scopelist) and the alphabetical sorting of the classifier names. The only decision-making necessary during the generation of the index is to suppress those classifiers associated with no provisions (common for very general classifiers), to delete those classifiers associated with too many provisions to be useful, and to delete provisions from the scope list of a classifier when the association is for purposes of arrangement only.

4.4.2 Proper Usage

Generate sparingly. Unlike the scopelist, the index may take considerable computer time to generate, and may provide too much information to analyze and evaluate thoroughly. Therefore, it is recommended that analyses and modifications be based on the scopelist generated, and the index be used only in the final phase of formulating a standard.

4.4.3 Representation

In SASE, an index is generated by the GENERATE INDEX command. There can be only one index for each VERSION of a standard. Therefore, the index does not have an explicit reference number. A SCOPELIST must have been previously generated.

The index may be specified as SIMPLE, with a single level of classifier headings, or SUBDIVIDED according to classifier levels, so as to break up large clusters of provisions. Certain classifiers may be DROPped from the index: by specific classifier numbers, by specific ROOTs of field or facets, or those whose scopelist exceeds a certain number or percentage of the total.

The DISPLAY INDEX command provides a number of options for displaying an index, which may include:

- all classifiers or only those of specific FIELDS or FACETs;
- all data items in the scopelists or only REQUIREMENTs or DETERMINATIONS;
- a COUNT of the data items in each scopelist rather than their listing.

4.5 Organization

The concepts of organization and outline are closely related. The reader should be comfortable with the material in both this section and in section 4.6 before creating extensive organizations and outlines for a standard.

4.5.1 Definition

An organization, or more precisely, its dual representation, an organizational tree, is a tree of classifiers formed by appending nuclear trees from various facets and fields. An organization is the list representation of its organizational tree, with the structure and classifiers in the tree converted into hierarchical headings in the organization. An organizational tree differs from a hierarchy (see section 4.2) in that the organizational tree is "built" one nuclear tree at a time (that is, one parent classifier and its immediate descendent classifiers), whereas for the hierarchy, once the root of a facet is included, the entire tree of that facet is included. An organization differs from an outline (see section 4.6) in that the

organization contains only the classifiers as headings, whereas the outline contains also the provisions entered at the appropriate headings.

In synthesis, the goal of the organization process is to assist standards writers in defining the scope of a new standard by identifying those combinations of classifiers that correspond to potential provisions. In expression, the goal is to assist users of an existing standard in quickly and reliably locating the relevant provisions by providing a logical arrangement for them. An effective organization, one that meets these goals, possesses five qualities:

1. Relevant: Each heading is significantly related to its provisions; it concisely expresses their scope.

2. Meaningful: The reader perceives the heading as being relevant to the provision.

3. Unique: The headings are distinct from one another to allow readers to access provisions unambiguously.

4. Complete: The total set of headings covers the entire scope of the standard and nothing more.

5. Graded: The headings show a regular gradation in scope through the levels.

Additional qualities are desirable for an efficient organization:

6. Progressive: The headings at any level are ordered in a pattern significant to the reader.

7. Intelligible: The depth (the number of levels in an organization) and breadth (the number of headings at one level) does not exceed the span of immediate memory of the reader.

8. Minimal: The number of headings is the minimum necessary for meaningful access.

9. Even: The organization divides the provisions so that depth and breadth do not vary greatly from one part to another.

Criteria for judging the effectiveness and efficiency of an organization can be developed for each of these qualities. Criteria for the first and second qualities--Relevant and Meaningful--can be evaluated completely only when an outline is developed from the organization; discussion of these qualities carries into section 4.6. Criteria for the other qualities can be evaluated on the basis of the ordering and grouping of the classifiers only. The ability to generate and evaluate alternative organizations before introducing the provisions is a valuable tool for both the synthesis and the expression of standards. An example of an organization was presented in the fire escape example in Chapter 2.

Use in Synthesis. The process of synthesizing a new standard includes the identification of provisions potentially to be included in the standard. This identification is accomplished in several stages. Iteration of the stages is normal.

In the first stage, a "top-down" classification is constructed. This must include at least one field for THING and one for REQUIRED QUALITY. Top-down classification is essentially a way of making decisions about scope, and then retaining those decisions as the criteria for completeness and relevance in the organization of a standard. It is practicable because the classification of the subjects and objectives of a standard automatically gives a classification for the THINGs and REQUIRED QUALITIES for the requirements of the standard. Classification has already been discussed in detail in section 4.1.

In the second stage, an organizational tree is constructed from the classification. The purpose of constructing the organizational tree is to produce the combinations of THING and REQUIRED QUALITY classifiers that correspond to provisions. The ordering of provisions is not of particular concern at this stage.

The construction of the organizational tree is presented as a formal algorithm below. This classifier-driven algorithm has not been implemented in SASE but is presented here as an aid to the reader constructing an organization manually using the available SASE tools.

The first step is to explode the trees of the classification into nuclear trees (recall that a nuclear tree is defined in section 4.1 as a classifier and its direct children). Thus, the process of appending trees into an organizational tree deals with one set of logical siblings at a time. The relations among and within facets are not forgotten in this step; each nuclear tree belongs to a certain facet and field, and the context conditions for a facet apply to each of the nuclear trees taken from it.

The second step is to select the root of one of the major THING or REQUIRED QUALITY fields as the root of the organizational tree. The process of appending begins with consideration of its first child, which is the first terminal node to be examined in step three.

The third step is the heart of the algorithm. Considering the classifiers on the branch from the root to any particular terminal node as the "stack", the stack and the remaining nuclear trees are examined to determine whether it is necessary, appropriate, or possible to append an additional nuclear tree. Because the model of a basic requirement has a THING as subject and a REQUIRED QUALITY as predicate, it is necessary to append another tree if the stack does not contain the root nuclear trees for the field of THING and the field of REQUIRED QUALITY. It is often appropriate that the stack contains more than one classifier for either or both of these two categories. The possibility of appending a nuclear tree is governed by the following rules:

1. Relevant: a nuclear tree whose parent is the root of a field may be appended at any location; a nuclear tree whose parent is the root of a facet but not a field may be appended when a class that the facet expands is present on the branch; and a nuclear tree whose parent is neither may be appended when a predecessor is on the branch.

2. Unique: only one nuclear tree may be appended to any single node of an organizational tree.

3. Graded: a nuclear tree may not be appended where a descendant of the tree is already on the branch.

4. Complete: all the siblings shall be retained when appending the nuclear tree.

5. Progressive: the order of the siblings in the organizational tree shall be the same as in the original classification.

6. Minimal: larger nuclear trees should be appended after smaller nuclear trees.

If the conditions are met, the nuclear tree is appended by "burying" the parent at the current terminal node and then processing to its first child. The third step is then repeated. If more than one nuclear tree are possible candidates, the most appropriate should be selected from due consideration of the consequences of the subsequent execution of step three. If no possibility of appending another tree exists, proceed to step four.

The fourth step is to select the next appropriate action once a branch is terminated. If the terminal classifier has a sibling remaining, proceed to it and execute step three for the new branch. If no sibling remains, examine the parent in the organizational tree (note that, in general, this would not be the parent of the nuclear tree). If that classifier is not a root of a field, the fourth step is repeated. If that classifier is a root and if no other fields remain that can be used to start a new tree (or a new "trunk"), then the algorithm is completed. If such fields remain, the root can be appended and the algorithm continued from step two.

If the resulting tree contains each field in the classification such that each terminal classifier from the root nuclear tree of each THING field is combined with each terminal classifier from the root nuclear tree of each REQUIRED QUALITY field, then the tree covers the scope of the classification. Note that different THING fields need not be combined and that descriptive REQUIRED QUALITY facets do not control any check for completeness. The order in which classifiers occur on a branch is not a factor in this algorithm (except for hierarchical considerations) although it is a consideration in some techniques for arrangements.

Several of the rules for appending nuclear trees used in this algorithm deserve further discussion. The first rule, Relevant, reflects the follow-

ing considerations. Fields are independent classifications; there is no situation where appending the root nuclear tree of a field would be irrelevant, provided the logical rules are not violated. Facets that are not the root of a field are not independent; they are a subdivision of some other class or classes in their field. Thus it would be irrelevant to append the root of a facet unless such a class is already in the organizational tree. For example, "Cast-in-place" and "Precast" are the siblings in a nuclear tree that serves to modify the class "Concrete". Appending that nuclear tree to "Steel" would be irrelevant.

For the nuclear tree that is not the root of a facet (the third type mentioned), the simplest rule for relevant appending would be that the parent of the nuclear tree must be present on the branch (not necessarily at the terminus). This has great intuitive appeal, but in practice it seems to be too rigid. Relevance depends a great deal on the specific context of the situation, but a few generalizations are in order. First, relevance is much less likely if an extended sibling is present on the branch. (An extended sibling is a classifier from the same facet that is neither a predecessor nor a descendent [See section 4.6].) Second, relevance is possible even through the parent is not present, as long as some predecessor is present. Strict application of a rule requiring the parent to be present ignores this second observation, introducing unwanted depth in organizational trees and reducing desirable flexibility.

A system for recording relations among facets is incorporated in SASE. It is designed to meet the need to determine the eligibility of a facet. In this system, each facet (except the root of a field) is attached to one or more "foster parents," which are simply other classifiers in the field. The foster parents need not be terminal classifiers on a facet. In addition, each link between a facet and a foster parent may be made conditional be specifying and recording a "context" (see section 4.1). Contexts take the form of conditions that given classifiers must be present or absent (in the organizational tree) for the relation between the foster parent and the facet to be relevant. For example, the facet "Concrete Pile Construction" may be appended when its foster parent "Pile" is on the branch of the organizational tree only if the classifier "Concrete" is also on the branch. (Use of such a system for checking the relevance between a classifier and argument for the purpose of provision entry requires a more thorough specification of the permissible links for successful use.)

The second rule, Unique, prevents the creation of "step siblings" in the organization. In the following example derived from [18], "Pile" and "Strength" have been made step siblings:

```
Foundation
     Soil
     Foundation Structure
          Strength
          Interrelationship
          Pile
               Existence
               Details
```

Because of this forced relationship, the question arises whether piles will be included in strength (and interrelationship) requirements for the foundation structure. Violation of this rule has been quite common in past models for organization.

Finally, it should be apparent that this classifier-driven algorithm can generate an extremely large organizational tree because of the assumed independence of the various fields and because of the requirement for completeness. The "top down" development of a classification advocated at the beginning of this section helps minimize the size of the resulting organizational tree.

Use in Expression. The capability to generate alternative organizations for a set of existing provisions is a key aspect of the SASE methodology. The needs for a method with enough rigor to preserve and promote the relevance and logic incorporated in the classification system and yet with enough flexibility to provide several arrangements might seem contradictory. Nonetheless, such a capability is central to SASE.

Compared to generating an organizational tree in synthesis, generating an organizational tree in expression does not demand the presence of at least one field for THING and one for REQUIRED QUALITY, nor does it require strict enforcement of the completeness rule for appending nuclear trees, because the resulting organization will serve only to order the existing provisions when they are outlined, not to identify all potential provisions. For the same reason, the organizational tree need not be a complete representation of the classification. It is conceivable that a single facet could lead to a useful ordering of a set of provisions. However, the organization must provide a location for each existing provision.

With these points in mind, the classifier-driven technique described in the preceding section "use in synthesis" can be used to generate alternative, or trial, organizations for an existing standard, and these organizations examined for the qualities discussed at the beginning of this section. It should be noted, however, that when the outline is subsequently generated, the majority of the branches in the organizational tree likely will be found not to have any provisions associated with them. This point is discussed further in section 4.6.

4.5.2 Proper Usage

Proceed from small to big. It is best to enter, examine, and modify smaller organizations corresponding to various grouping of facets before entering an organization for an entire version.

Use as "template" for outlining. Since fewer decisions are required for generating an organization than for generating an outline, it is advisable to experiment with several organizations before proceeding to building a complete outline.

4.5.3 Representation

In SASE, an organization is generated by the ENTER ORGANIZATION command. (It can also be generated concurrently with an outline. See section 4.6.) Since there may be alternative organizations within a VERSION of a standard, the organization is given a reference number.

The organization is built in a dialogue form. For each line of input, the user specifies a classifier to serve as the heading, and the hierarchical position of that heading on the organization tree. For the latter, two options are provided:

- if the LEVEL qualifier is used in the command, the user directly specifies the hierarchical level to be assigned to the classifier entered.

- if the PARENT qualifier is used in the command, the user enters the heading number previously assigned to the parent of the classifier entered; SASE automatically assigns a hierarchical level to the classifier equal to the parent's level plus one.

Entry by the PARENT option is recommended, as this is the only way to ensure that the hierarchical relation of the nuclear trees is properly reflected in the organization.

Since entry of a sizeable classification is time-consuming, the user can END the dialogue to any time and resume entry using the CONTINUE ORGANIZATION command.

The MODIFY ORGANIZATION permits various rearrangements, including:

- INSERTing specific headings by LEVEL or PARENT, as above;

- DELETing a specific heading or a set of headings;

- DUPLICATing or MOVing a specific heading or set of headings to a specified position.

- MODIFYing a specific classifier, its level or its parent in the organization.

The DISPLAY ORGANIZATION command provides a number of options for displaying an organization:

- the display can be in indented or tabular form;

- the tabular form can include any attributes of the classifiers serving as headings.

4.6 Outline

4.6.1 Definition

An outline is a list representation of the scope of a standard. It consists of a hierarchical arrangement of the classifiers as headings of sections (i.e., an organization) with the provisions of the standard entered under the appropriate headings.

The goal for the process of outlining a standard is to find the best linear order of the provisions in the list--the order that maximizes the desired qualities of organization described in section 4.5. Outlining differs from indexing in the necessity for logical rigor. Because an outline is intended to provide a single point of access for every provision, logical unambiguity is more important than it is for indexing, in which classing a provision by two siblings is acceptable. (Note that the outlining process does not guarantee that a provision will appear only once in the outline; this problem is taken up in the discussion of provision entry.)

The approach advocated here involves two activities:

1. Generating alternative outlines with strategies that promote the desirable qualities.

2. Measuring the qualities of different outlines to compare their overall goodness for the specific intended use.

This approach has the advantage of being able to provide different outlines of the same provisions for different users. Only the generation of the outlines is discussed in this report. Much of the basis for preference of one outline over another is individual and subjective; hence, little guidance can be given on measuring the quality of an outline. A discussion of several useful measures is presented in [9].

The generation of an outline from a classification for a set of provisions logically proceeds in two steps: first, an organizational tree is generated by appending nuclear trees of classifiers together, then provisions are entered on the branches of the tree according to their arguments. In SASE, these steps can be taken separately by first generating an organization from the classification, as described in section 4.5, and then generating an outline from it, or the steps can be taken together in an interactive input mode to generate an outline (including its organization) directly from the classification.

The techniques of creating an outline are discussed in more detail in the following two subsections. First, the methods for generating organizational trees are reviewed; then, criteria for entry of a provision on a branch of an organizational tree are discussed.

Generation of organizational trees. The rules for appending nuclear trees to an organizational tree described in section 4.5 can be modified when the goal is the generation of an outline for existing provisions. Now two

different criteria are available for making the decision to cease the extension of a branch and move on to the next branch: the absence of any qualified nuclear trees or the absence of an eligible provision. The first criterion was used in the classifier-driven technique presented in section 4.5. Classifier-driven techniques allow one to maintain the completeness of the classification system in the organizational tree, and thus to check the completeness of the provisions. However, nearly all techniques for generating outlines for an existing set of provisions make use of the second criterion; they may be termed "provision driven." Classifier-driven techniques are not often used for expression of existing standards because the resulting organizational trees are extremely large and the majority of their branches do not have provisions associated with them.

The reason that classifier-driven techniques develop so many empty branches is that the assumption of independence between the fields is not warranted. Consider the analysis of the seismic provisions [18], and the classification system for it given in figure 4.3. If the 21 facets in the "Physical Entity" field were independent (obviously they are not, nor are they assumed so) an organizational tree fully incorporating all of them would have over three billion branches (the product of the terminal branches of the 21 facets). The most conservative estimate for the number of branches in an organizational tree for that classification would proceed as follows: assume that the "Physical Entity" field is one tree with no interaction (a false assumption), thus having 62 branches (the sum of the terminal classifiers of its facets), and assume that the 21 branches of the "Process" field (not shown) combines additively, not multiplicatively, with it to give all THINGS possible for subjects of Requirements (also a false assumption). Ignoring other possible fields, estimate the total number of branches as the product of the 12 branches of the REQUIRED QUALITY field (also not shown) and the 79 branches of the combined subject fields. The total thus obtained is 948, whereas the total number of requirements found in that study is 242. It does not appear that the number would approach 948. The assumption regarding the "Physical Entity" field having only 62 branches is quite extreme. Thus, a more realistic assumption would result in a number of branches far in excess of 948.

The drastic pruning of the branches of the actual organizational tree compared to the complete tree occurs because there are many situations in which it is correct to append only a portion of a nuclear tree, leaving some of the siblings off the organizational network. Provision-driven techniques allow this.

A problem that arises in generating an organizational tree for outlining purposes is that some provisions are of a more general nature than others, and therefore strict application of the Graded criterion for provision entry frequently will prevent the entry of the more general provisions in an organizational tree. It is possible to overcome this problem by expanding the classification system. Such was the reason for including the facet "Material Nature" with the sons "Material Generic" and "Material Specific" in the classification for the seismic provisions (figure 4.3). This small

facet was appended in conjunction with the material types thus:

Material Generic
Material Specific
  Wood
  Steel
  Concrete
  Masonry

This allowed otherwise identical branches to be constructed so that both general and specific provisions could be outlined without forcing "Wood," "Steel," and so forth, to become siblings of other classifiers to which they were logically unrelated.

<u>Entry of provisions in an organizational tree.</u> Entry depends upon the comparison of the set of classifiers that compose a branch of an organizational tree with the set of outlining arguments for a provision. The comparison reveals whether the provision is appropriately identified by the classifiers on the branch. The decision to enter a provision is based on four criteria which follow from the qualities necessary for an effective organization of a standard (see section 4.5) as follows:

1. Relevant: each classifier on the branch must be related to one of the provision's outlining arguments.

2. Complete: each outlining argument of the provision must be included among the set of classifiers on the branch.

3. Unique: no classifier on the branch may be a "cousin" (This concept is defined subsequently) of any outlining argument.

4. Graded: no classifier on the branch may be a descendant of any outlining argument.

The decision does not depend on the desirable qualities Even, Minimal, and Progressive because they are not relevant in the context of a single branch of an organizational tree. The quality Meaningful is achieved automatically the arguments for each provision have been selected properly. It is possible to consider a limit on the number of nodes on a branch as a criterion for the quality Intelligible.

Each of the four criteria depends on the logic of the classification system. Since a faceted classification system need not be strictly logical, checking of the criteria becomes complex. As mentioned in section 4.2, it is possible to combine all the facets in a field into a single large facet, but frequently it is also possible to combine the facets in a relevant fashion into a large tree that is not completely logical. The problem is to define clearly how the qualities can be attained with a less than perfectly logical classification system.

Given a faceted system, the criterion for the quality Relevant is easily described in three steps. Each classifier on the branch must pass the

criterion for the provision in question to qualify for entry on the branch. The three steps are:

1. A classifier that is an argument of the provision is relevant.

2. A classifier from the same facet as an argument is relevant if it is a logical predecessor of the argument. (A logical predecessor is the parent, the parent of the parent, etc.)

3. A classifier from the same field, but not the same facet, as an argument is relevant if it is a logical predecessor of the argument in a large tree of combined facets.

The second test can be extended to say that a classifier from the same facet as an argument is not relevant unless it is a predecessor of the argument (assuming it failed the first test). Making this extension means that the criteria for the qualities Unique and Graded mentioned previously are automatically included, as far as facets are concerned. As shown in figure 4.7, there are four possibilities for a classifier and an argument from the same facet: the classifier is a predecessor, descendent, or cousin of the argument or is the same as the argument. As shown in figure 4.7, a cousin includes the siblings, the siblings of the predecessors, and any descendants of such siblings. The third test for the quality Relevant cannot be similarly extended, (that is, it cannot be used to disqualify a provision simply because one classifier fails the test), because the possibility of illogical siblings leaves the possibility that the classifier may be relevant for another argument for the same provision.

The principal problem in using these tests for the quality Relevant is that a complete specification of the permissible interconnections of the facets is required as a part of the classification system. Otherwise a potentially relevant classifier that is not traceable to any argument will disqualify a provision from appearance on the appropriate branch. A system for recording and using relations between facets is included in SASE.

An added problem is that the tracing of the permissible interconnections among facets involves significantly more checking than any other tests employed for entry of a provision on a branch.

There is a less stringent criterion for the quality Relevant that frequently is good enough to produce useful outlines. The criterion combines well with the relatively simple criteria for the qualities Unique and Graded, which tend to prevent irrelevance in addition to delivering their named objectives. The criterion is quite simple: the last classifier on the branch must be an argument of the provision. It is accomplished efficiently by selecting those provisions in the scope list of the last classifier and discarding all others. Since it is the last classifier on the branch, it also has the desirable feature of limiting the provisions to be checked by the other criteria in an intuitively optimal fashion. For convenience, this less stringent criterion is called "local relevance." Useful outlines may be obtained employing the local relevance criterion without any of the other criteria. Methods of synthesizing organizational

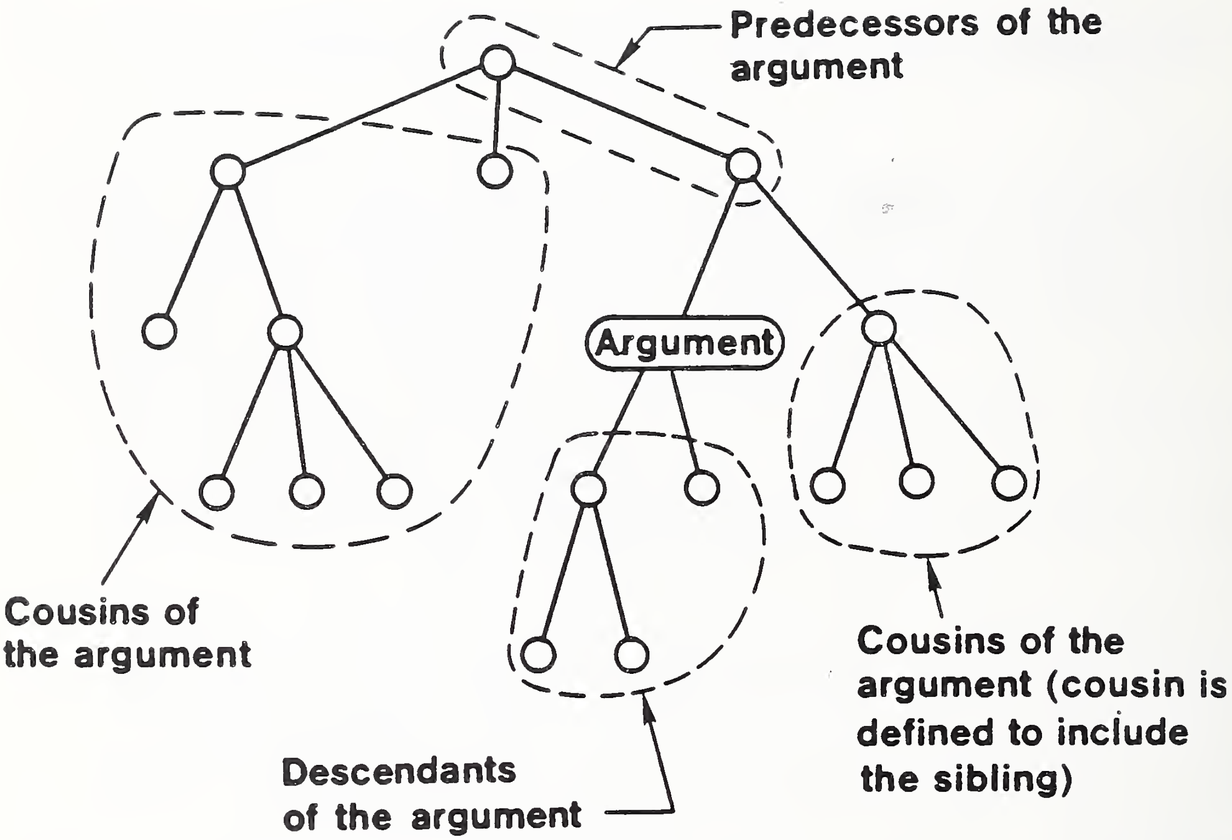

Figure 4.7 Partition of a tree into logical regions.

trees, described in section 4.5, tend to promote the validity of the local relevance criterion.

The criterion for the quality Complete assures that a provision is not prematurely entered into an outline. It has nothing to do with assuring that all provisions are outlined, another aspect of completeness. The criterion is independent of the question of relevance, and it is applied conveniently immediately following the local relevance criterion. For each provision passing the local relevance criterion, a check is made to see that each of its arguments is among the classifiers on the branch.

A separate check for the quality Unique at the facet level often is useful when the full relevance criterion is not employed. The criterion disqualifies any provision with an argument that is a cousin of one of the classifiers on the branch.

A separate check for the quality Graded at the facet level often is also useful when the full relevance criterion is not employed. The test is convenient to apply in conjunction with the Unique criterion just described, because of the nature of the task of partitioning a tree as shown in figure 4.7. Redundant, therefore ambiguous, locations for provisions may be a common defect in outlines developed without use of the graded criterion. Because logic is not preserved above the facet level it is not possible to apply criteria for Unique or Graded above that level.

A common defect in an outline that satisfies all the criteria except full relevance is the entry of a single provision on more than one branch of the organizational tree. The ambiguity usually arises from the use of a facet that is not exhaustive. (A facet is exhaustive if its combined scope list includes all provisions.) For example, consider a provision from the analysis of the seismic provisions for buildings with the arguments: "Part of Building," "Material Specific," and "Masonry." It would meet all criteria except full relevance for both of the following branches of classifiers:

(i)	(ii)
Part of Building	Part of Building
Structural	Nonstructural
Material Specific	Material Specific
Masonry	Masonry

The problem is that Structural and Nonstructural are not exhaustive; the provision could apply to either. Using the full relevance criterion, the provision would not qualify for either branch.

Even the full relevance criterion is not guaranteed to prevent all redundant entry of provisions, unless the fields are strictly logical. Consider the same provision just described and the following branches of classifiers:

(i)	(ii)
Part of Building Material Specific Component Masonry	Part of Building Material Specific Masonry

"Component" belongs to a facet that can be used to distinguish among various "Parts of Buildings", and "Masonry" belongs to a facet that may be used to distinguish among various "Components." The former fact means "Component" is not out of place in the branch, and the latter fact means that "Component" can be a predecessor of "Masonry," thus satisfying the full relevance criterion. Since "Component" is not an argument, the completeness criterion is satisfied for either branch. Thus the provision qualifies for both branches--an ambiguous situation.

Three possible solutions for this problem exist. The first possible solution is to enforce the logical rules for the entire classification. For reasons already explained, however, fully logical classifications are not always desirable or possible.

The second possible solution is to strengthen the full relevance criterion by requiring that each of the classifiers on the branch be an argument or the direct predecessor (within the same facet) of an argument. This would avoid tracing the relations between facets. It has the disadvantage of requiring added identification and storage of arguments. For example, consider the following five arguments for a requirement giving the minimum amount and spacing of reinforcement in a cased concrete pile:

Pile, Reinforced Concrete, Cased,
Reinforcement, Quantities and Dimensions

With the exception of "Quantities and Dimensions," which is a child of "Required Quality," these arguments appear in the physical entity field shown in figure 4.3. Now, consider the application of the strengthened relevance criterion against the following list of classifiers which clearly represents an appropriate branch for the provision (compare figure 4.3):

Building	- does not qualify
Required Quality	- direct predecessor of "Quantities and Dimensions"
Part of Building	- does not qualify
Structural	- does not qualify
Foundation	- does not qualify
Foundation Structure	- direct predecessor of "Pile"
Pile	- is an argument
Quantities and Dimensions	- is an argument
Reinforcement	- is an argument
Reinforced Concrete	- is an argument
Cast-in-place	- direct predecessor of "Cased"
Cased	- is an argument

The requirement fails to qualify for this branch based on the strengthened criterion. The addition of "Foundation" as an argument for the requirement would qualify "Foundation" trivially and "Structural" because it is a direct predecessor. The addition of "Part of a Building" as an argument would qualify "Part of Building" and "Building" in like fashion. The requirement would then pass the strengthened criterion. For this provision, it is not a large problem to add two arguments, but it could be for others. Furthermore, it seems redundant because the argument "Pile" clearly implies that all of those higher order classifiers are relevant.

The third possible solution is to develop a more complete and explicit set of rules for tracing the relations among facets. One such test not included in the present system is to require that the argument indirectly related to the classifier must follow that classifier (not necessarily immediately) on the branch. Another is that the branch of classifiers contain at least one classifier from each facet involved in the linkage.

Given that the relevance criterion is divided into two criteria, local and full, and that the full relevance criterion will not always be used, an efficient strategy for computer processing emerges:

1. Apply the local relevance criterion.

2. For each provision passing the local relevance criterion, test each argument for the Complete, Unique, and Graded criteria, in that order.

3. For each provision passing those criteria, test each of the set of classifiers for the full relevance criterion, disqualifying the provision if any classifier fails. The full relevance criterion is actually applied in three steps, repeated here for convenience: the classifier is relevant if it is an argument or it if it is a logical predecessor of an argument, either within or outside the same facet.

Such an approach is included in SASE. The application of all three criteria is optional: testing may stop after any criterion, if desired.

A recommended strategy is to begin outlining using all criteria relaxing the application of the later criteria if logical problems seem to preclude the development of outlines that can include all the provisions. The alternate strategy of beginning to outline without the more rigorous criteria, and resorting to them only if necessary to reduce the redundant occurrences of provisions has the advantage of less costly computer processing, but it has the disadvantage of letting irrelevant, and sometimes illogical, outlines be developed.

In summary, two independent criteria--Relevant and Complete--lead to five criteria that work in a faceted classification system: local relevance, Complete, Unique, Graded, and full relevance. It is possible to develop good outlines without using all the criteria, but ambiguities and inconsistencies are less likely when using all the criteria. Because it still is

possible to develop outlines with more than one position for a provision when using all the criteria, more study of the fifth criterion and of the logic of faceted systems is in order.

The development of an algorithm capable of automatically and completely generating an organizational tree and outline in a provision-driven mode and with a faceted classification system appears to be a formidable task. SASE contains a semi-automatic, interactive computer algorithm. With respect to the criteria for appending nuclear trees presented earlier in this section, the algorithm operates as follows:

1. Relevant: no explicit check is made

2. Unique: appending more than one nuclear tree to a single node is possible, but only on explicit command of the user.

3. Graded: no explicit check is made.

4. Complete: no explicit check is made in most situations--this is not a classifier driven algorithm.

5. Progressive: the normal order of the classification is automatic, although it is possible for the user to override it.

6. Minimal: the order of appending is completely up to the user.

The lack of explicit checks for Relevant and Graded is not intended to imply that they are thought unnecessary. Rather, their incorporation is advocated. They are not in the present SASE computer algorithm only because the algorithm was developed to test various criteria for provision entry rather than nuclear tree appending. A test for Relevant may be more problematic, as discussed. Various criteria should be tested for workability, because incorporation of such a test would be an important step in the development of a completely automatic algorithm.

The interactive algorithm is provision driven. Once the user has entered a branch, the algorithm determines which provisions have the potential to be outlined on the branch should additional classifiers be appended to it. The algorithm will also specify those classifiers upon request. The user then continues by either appending another nuclear tree, or moving on to the next branch.

4.6.2 Proper Usage

First develop a satisfactory organization (see section 3.5). Even with an organization as a "template" the user must proceed thoughtfully to obtain the desired qualities for an outline. A logically unambiguous location must be provided in the outline for each provision.

4.6.3 Representation

In SASE, an outline is generated by the GENERATE OUTLINE command. Since there can be only one outline within a VERSION of a standard, the outline does not have an explicit reference number.

There are two basic options for generating an outline:

- FROM a previously entered ORGANIZATION; or
- STEPWISE, in a dialogue form similar to ENTER ORGANIZATION.

The user can further specify:

- whether ALL classifiers are to appear in the outline or only those with relevant provisions;
- whether all data items are to be included or only REQUIREMENT or DETERMINATION;
- DROPping specified CLASSIFIERs, FIELDs, or FACETs from the outline; and
- criteria for ENTRY (see above).

In the STEPWISE option, each heading (classifier) and its associated provisions (data items) are generated in two cycles of the dialogue:

- the user first enters a classifier to serve as the heading and its hierarchical level in the outline (the heading may be a specific CLASSIFIER or indirectly a descendant of a specified PARENT);
- the user specifies the provisions meeting the ENTRY criterion to be entered under the heading; alternately, the user can first ask SASE to LIST the qualified candidate provisions and then specify the ones to be entered.

Since generated of a sizeable outline is time-consuming, the user can END the dialogue at any time and resume generation using the CONTINUE OUTLINE command.

The DISPLAY OUTLINE command provides a number of options for displaying an outline:

- the display can be indented or tabular form;
- ALL or only specified classifier attributes can be included;
- ALL data items or only REQUIREMENTS or DETERMINATIONS can be included under each classifier; and
- ALL or only specified data item attributes can be included.

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APPENDIX A. ANALYSIS OF A STANDARD FOR CONCRETE QUALITY

A.1 Introduction

To provide a practical demonstration of the SASE methodology for the rational analysis and expression of standards, the results of a study of a standard for concrete quality are presented in this appendix. The subject standard comprises all of Chapter 4, "Concrete Quality", of the American Concrete Institute's Building Code Requirements for Reinforced Concrete (ACI 318-77) [1]. Virtually all of the SASE techniques for analyzing and expressing a standard were applied in the study.

A.2 Technical approach

The study was conducted in the order of the steps for the rational analysis and expression of an existing standard described in Chapters 3 and 4 of this report. In summary, these steps are to:

1. identify the derived (requirements and determinations) and input data items in the text of the standard;

2. develop decision tables to model the logic of the requirements and determinations;

3. develop a global ingredience network systematically linking the requirements and determinations contained in the standard;

4. classify the requirements and determinations to determine the scope of the standard and for outlining and indexing the contents; and

5. organize logically the contents of the standard.

As described in Chapter 1 of this report, reviewing the subject matter with experts during the course of analysis and expression was found in the study to be essential. Such interaction was especially valuable wherever multiple interpretations of the text seemed possible, and where SASE analysts noted the text of the standard to be ambiguous or incomplete. Particularly important times for interaction between subject matter experts and SASE analysts were: (1) after requirements and determinations had been (tentatively) identified and a draft ingredience network had been developed, and (2) while draft organizational outlines were being developed.

A.3 Results

The results are presented in this section in the same order as the steps taken in the study. The figures and tables discussed in this section are grouped at the end of the appendix for easy reference.

A.3.1 Data items

The text of the standard for concrete quality, indicating the location of individual data items (annotated with datum reference number; see section A.3.3 below), is shown in figure A.1. The derived data items are listed in SASE-format in figure A.2 and the input data items are listed in SASE-format in figure A.3. The notation used includes (see Chapter 3 of this report):

- REFE: datum reference number (numbers below 1000 denote derived data items; those above denote input data items).
- NAME: a datum identifier.
- SECT: section of the standard containing the datum (delimiting periods omitted).
- PAGE: page of Chapter 4 of the standard containing the datum.
- VALU: boolean for requirements; boolean, boolean vector, or numeric for determinations.
- SOUR: source of the datum, i.e., either input or derived.
- TYPE: type of datum, i.e., either decision table or function.
- STAT: either classified (linked with at least one classifier) or unclassified.
- UTIL: utilization of the datum, i.e., either requirement or determination.
- TITL: text string providing a descriptive title of the datum.
- INGREDIENTS: reference numbers of data items ingredient to the datum, or data items upon which the datum is dependent.
- ARGUMENTS: reference numbers of classifiers linked to the datum.
- EQUIVALENTS: cross references with other data items, by datum reference numbers (not used in the present example).
- COMMENT: text string containing explanatory information.

The distribution of the data items in the standard (see figure A.1) shows that the text is not uniformly complex. The subdivision of the text into numbered paragraphs implies that each paragraph is a discrete unit of information. In some instances, there is, in fact, a one-to-one correspondence between a datum and a numbered paragraph. On the other hand, in some instances, several data items correspond to a single numbered paragraph, and, in some instances, a datum corresponds to an entire major heading encompassing several numbered paragraphs.

A.3.2 Decision Tables

Any datum of type REQUIREMENT may be expressed as a decision table, and with the use of this aid may be analyzed for completeness and clarity. The general form for a decision table representation of a datum is discussed in section 3.3 of this report. The decision table for a requirement datum specifies a set of conditions (each of which may be true, false, or irrelevant during the evaluation of the datum), combinations of which (i.e., rules) yield either of two actions: that the requirement is satisfied or violated. In practice, requirements with only a single condition frequently are found in the text of a standard. One example found in the text of figure A.1 is: "Requirement for the specification of concrete strength on design drawings," datum reference number 10. The single condition here is whether or not concrete strength has in fact been specified on the drawings. If it has, then the requirement is satisfied. If not, then the requirement is violated. The analysis of such a requirement's completeness and clarity would not be enhanced by the development of a decision table. For this reason, decision tables were developed in this study only for data items with two or more conditions.

Data items of type DETERMINATION also may be expressed as decision tables. Unlike tables for REQUIREMENT data items, however, rules in DETERMINATION tables may yield actions that return numerical or nominal values. An example is the "determination of standard deviation," datum reference number 70. In this example, rules 1 and 2 yield the nominal scalar value: "standard deviation computed by statistics." The standard deviation is not defined for any other rule.

Once entered in SASE, the decision tables were analyzed by generating decision trees. This analysis checked the decision tables for logical consistency. In addition, this analysis determined explicitly the else rules associated with each decision table. A list of all possible combinations of conditions leading to the else rule in a decision table is very helpful to the SASE analyst in determining whether the corresponding provision is complete in its scope. The decision tables for the standard for concrete quality are presented in SASE-format in tables A.1 to A.11, along with their associated tables of else rules as generated by SASE.

A.3.3 Global ingredience

Once the individual data items were entered into SASE along with their ingredient data items, the global ingredience network was generated to thread all the data items together. Figure A.4 displays the global ingredience network for the standard for concrete quality arranged in order of the requirements.

An exploded segment of the global ingredience network is displayed in figure A.5 to provide a guide to the interpretation of a SASE-generated network. Datum 181 is the only output requirement in this segment and lies at level 0 in the network. Datum 182 is a direct ingredient of this output requirement and lies at level 1. Datum 60 is also a direct ingredient of

the output requirement but, perhaps counter-intuitively, it lies at level 2. A property of the algorithm that displays networks in SASE is that first the innermost level at which each datum lies anywhere in the network is determined and then each datum is displayed at this innermost level everywhere it appears in the network. Thus, datum 60, which is a direct ingredient of the output requirement lies at level 2 in the network because that is the innermost level it occupies as a consequence of being a direct ingredient of datum 182 also. This level-spanning property of the display algorithm results in a network that is easier for a SASE analyst to assess in terms of flows of information.

Figure A.5 also illustrates the SASE notation for network entries. The reference number in the second (and any following) occurance of datum 60 is preceded by a minus (-) sign to indicate that this datum has occured before in the display of the network. The asterisk (*) following the reference number in its second (and any following) occurance indicates that datum 60 has ingredient data items and that these have been listed previously in the display of the network.

A.3.4. Classification and scope

The ability to access relevant information in a standard depends on the clarity and completeness of the classification scheme used to organize the standard. The basic elements of the classification scheme are the classifiers, which denote the entities and attributes pertinent to the data items in the standard. Section 4.1 of this report treats classification in detail. Classifiers appropriate for accessing information in the standard for concrete quality are listed in figure A.6. The notation used includes (see Chapter 4 of this report):

REFE: classifier reference number.

NAME: a character string used to identify the classifier.

TYPE: ACT(ive) denotes that the classifier will be displayed in an Outline; no entry indicates that the classifier will not be displayed.

PARE: specifies the reference number of the single classifier which is the parent of the current classifier in the facet (see Chapter 4 of this report).

TITL: text string providing the full classifier name.

FOSTER: specifies the reference numbers of multiple parents in different fields (see Chapter 4 of this report).

COMMENT: additional explanatory notes.

The scope of the standard is established once pertinent classifiers have been assigned as arguments to all the data items. The scope is this set of pertinent classifiers. The SASE-generated scopelist for the standard for

concrete quality is given in figure A.7. The scopelist is displayed in the numerical order of the classifiers. Another convenient way to illustrate the scope of the chapter is by means of an index, which is displayed in the alphabetical order of the classifiers. The SASE-generated index for the standard for concrete quality is given in figure A.8. In both the scopelist and index, the data items associated with any single classifier are listed in datum reference number sequence.

A.3.5 Organization

This study of the standard for concrete quality sought not only to analyze the text of the standard in terms of its technical content but also to illustrate the utility of SASE in manipulating the organization of the text without modifying the technical contents. As described in Chapter 4 of this report, SASE enables the user to organize trees of classifiers that will produce the desired information structure (which may vary depending on the user's view and requirements of this information). Once the user has established a structured organization of classifiers, SASE can generate a full outline. The outline expresses the organization, and also displays the data items associated with the various classifiers. A SASE-generated outline for the standard for concrete quality is shown in figure A.9. Comparison of this outline with the text in figure A.1 will show that their arrangements differ. The outline shown here is based on a revised organization for the standard suggested by the analysis of its technical contents.

A.4 Enhanced understanding of a standard through SASE-based analysis

During this study the analysts consulted subject matter experts to ascertain that the technical content of the standard was interpreted properly, and to check the correctness and usefulness of the SASE-based analysis. Chief among the experts consulted was the chairman of the ACI committee responsible for Chapter 4 "Concrete Quality" of the ACI 318 standard. Several questions and recommendations for clarifying aspects of this chapter, following from the SASE-based analysis, were revealed in the consultations. In particular:

1. Section 4.1.1 says that the overall scope of Chapter 4 is to minimize the frequency of strength tests falling below f'c. However, this objective is not a requirement of any provision of the chapter. A more accurate statement of the chapter's scope may be: to realize the intentions of the designer, i.e., to achieve the specified f'c in the structure.

2. Chapter 4 does not provide for the proportions of the entire mix, and only stipulates requirements for water-cement ratio.

3. A clause within section 4.4.3 concerning the required average test strength of concrete from a facility without an adequate record is simply a restatement of a clause appearing within section 4.3.1. The clause seems irrelevant to the remainder of section 4.4.3, and

in this instance, the redundancy may be a source of confusion for the user of the standard.

4. Having defined required average test strength of concrete, Chapter 4 never requires its use.

5. Section 4.5.1 specifies that where suitable data from field tests or laboratory trial batches are not available, permission to base concrete proportions on water-cement ratio limits may be granted. However, the provision does not specify who may grant such permission. Two possible choices are the project engineer and the building official.

6. The clarity of Chapter 4 would be enhanced through the use of a symbolic representation for required average compressive strength, namely f'cr, which is used only in the accompanying commentary.

7. Chapter 4 should provide an explicit method for computing f'cr used as a basis for selecting concrete proportions. Equations 4-1 and 4-2 in the accompanying commentary provide such a method.

8. Chapter 4 lacks a definition of sufficiency of data required to justify reducing target compressive strength.

The reader is invited to study Chapter 4 "Concrete Quality" of the 1983 edition [2] of the ACI 318 standard and compare it with the results of this study to see how some of the above questions and recommendations have been addressed.

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PART 3 – CONSTRUCTION REQUIREMENTS

CHAPTER 4 – CONCRETE QUALITY

4.0 – Notation

f'_c = specified compressive strength of concrete, psi

f_{ct} = average splitting tensile strength of lightweight aggregate concrete, psi

4.1 – General

4.1.1 – Concrete shall be proportioned and produced to provide an average compressive strength sufficiently high to minimize frequency of strength tests below the value of the specified compressive strength of concrete, f'_c. See Sections 4.3.1 and 4.8.2.3.

4.1.2 – Requirements for f'_c shall be based on tests of cylinders made and tested as prescribed in Section 4.8.

01 4.1.3 – Unless otherwise specified, f'_c shall be based on 28-day tests. For high-early-strength concrete, the test age for f'_c shall be as indicated in the design drawings or specifications.

10 4.1.4 – Design drawings submitted for approval or used for any project shall show the specified compressive strength of concrete f'_c for which each part of the structure is designed.

20 4.1.5 – Where design criteria in Sections 9.5.2.3, 11.2 and 12.2.3(c) provide for use of a splitting tensile strength value of concrete, laboratory tests shall be made in accordance with "Specifications for Lightweight Aggregates for Structural Concrete" (ASTM C 330) to establish value of f_{ct} corresponding to specified value of f'_c.

30 4.1.6 – Splitting tensile strength tests shall not be used as a basis for field acceptance of concrete.

4.2 – Selection of concrete proportions

40 4.2.1 – Proportions of materials for concrete shall be established to provide:

(a) Adequate workability and proper consistency to permit concrete to be worked readily into the forms and around reinforcement under conditions of placement to be employed, without excessive segregation or bleeding

(b) Resistance to freezing and thawing and other aggressive actions, as required by Section 4.6

(c) Conformance with strength test requirements of Section 4.8

4.2.2 – Where different materials are to be used for different portions of the work, each combination shall be evaluated separately.

4.2.3 – Concrete proportions, including water-cement ratio, shall be established on the basis of field experience (Section 4.3) or laboratory trial batches (Section 4.4) with materials to be employed, except as permitted in Section 4.5 or required by Section 4.6.

4.3 – Proportioning on the basis of field experience

4.3.1 – Where a concrete production facility has a record, based on at least 30 consecutive strength tests that represent similar materials and conditions to those expected, required average compressive strength used as the basis for selecting concrete proportions shall exceed required f'_c at designated test age by at least:

400 psi if standard deviation is less than 300 psi 60
550 psi if standard deviation is 300 to 400 psi
700 psi if standard deviation is 400 to 500 psi
900 psi if standard deviation is 500 to 600 psi

If standard deviation exceeds 600 psi, concrete proportions shall be selected to produce an average strength at least 1200 psi greater than required f'_c.

4.3.2 – Strength test data for determining standard deviation shall be considered to comply with Section 4.3.1 if data represents either a group of at least 30 consecutive tests or a statistical average for two groups totaling 30 or more tests.

4.3.3 – Strength tests used to establish standard deviation shall represent concrete produced to meet a specified strength or strengths within 1000 psi of that specified for the proposed work. 70

4.3.4 – Changes in materials and proportions within the population of background tests used to establish standard deviation shall not have been more closely restricted than for the proposed work.

Figure A.1 Text of a standard for concrete quality [1] with datum reference numbers annotated in the margins.

TABLE 4.5 — MAXIMUM PERMISSIBLE WATER-CEMENT RATIOS FOR CONCRETE WHEN STRENGTH DATA FROM TRIAL BATCHES OR FIELD EXPERIENCE ARE NOT AVAILABLE

Specified compressive strength, f'_c, psi*	Maximum permissible water-cement ratio			
	Non-air-entrained concrete		Air-entrained concrete	
	Absolute ratio by weight	U.S. gal. per 94-lb bag of cement	Absolute ratio by weight	U.S. gal. per 94-lb bag of cement
2500	0.67	7.6	0.54	6.1
3000	0.58	6.6	0.46	5.2
3500	0.51	5.8	0.40	4.5
4000	0.44	5.0	0.35	4.0
4500	0.38	4.3	†	†
5000	†	†	†	†

*28-day strength. With most materials, water-cement ratios shown will provide average strengths greater than indicated in Section 4.3.1 as being required.

†For strengths above 4500 psi (non-air-entrained concrete) and 4000 psi (air-entrained concrete), proportions shall be established by methods of Sections 4.3 or 4.4.

4.4 – Proportioning by laboratory trial batches

4.4.1 – When laboratory trial batches are used as the basis for selecting concrete proportions, strength tests shall be made in accordance with "Method of Test for Compressive Strength of Cylindrical Concrete Specimens" (ASTM C 39) on cylinders prepared in accordance with "Method of Making and Curing Test Specimens in the Laboratory" (ASTM C 192).

4.4.2 – When laboratory trial batches are made, air content shall be within ±0.5 percent and slump
182 within ±0.75 in. of maximums permitted by the specifications.

4.4.3 – A curve shall be established showing relationship between water-cement ratio (or cement content) and compressive strength. Curve shall be based on at least three points representing batches which produce strengths above and below required average compressive strength specified in Section 4.3.1. If concrete construction facility does not have a record based on 30 consecutive strength tests representing similar materials and conditions to those expected, required average compressive strength shall be 1200 psi greater than f'_c. Each point shall represent the average of at least three cylinders tested at 28 days or the specified earlier age.

4.4.4 – Maximum permissible water-cement ratio (or minimum cement content) for concrete to be
181 used in the structure shall be that shown by the curve to produce the average strength indicated in Section 4.3.1 or 4.4.3 unless a lower water-cement ratio or higher strength is required by Section 4.6.

4.5 – Proportioning by water-cement ratio

200 **4.5.1** – If suitable data from a record of 30 consecutive tests (Section 4.3) or from laboratory trial batches (Section 4.4) are not available, permission may be granted to base concrete proportions on water-cement ratio limits in Table 4.5.

4.5.2 – Table 4.5 shall be used only for concrete to be made with cements meeting strength requirements for Types I, IA, II, IIA, III, IIIA, or V of "Specification for Portland Cement" (ASTM C 150), or Types IS, IS-A, IS(MS), IS-A(MS), IP, IP-A, or P of "Specification for Blended Hydraulic Cements," (ASTM C 595), and shall not be applied to concrete containing lightweight aggregates or admixtures other than those for entraining air.

4.5.3 – Concrete proportioned by water-cement ratio limits prescribed in Table 4.5 shall also conform to special exposure requirements of Section 4.6 and to compressive strength test criteria of Section 4.8.

4.6 – Special exposure requirements

4.6.1 – Concrete that, after curing, will be exposed to freezing temperatures while wet shall contain 230
entrained air within limits of Table 4.6.1, and in addition:

4.6.1.1 – For concrete made with normal weight aggregate, water-cement ratio shall not exceed 250
0.53 by weight.

4.6.1.2 – For concrete made with lightweight aggregate, specified compressive strength f'_c 240
shall be at least 3000 psi.

TABLE 4.6.1 — CONCRETE AIR CONTENT FOR VARIOUS SIZES OF COARSE AGGREGATE

Nominal maximum size of coarse aggregate, in.	Total air content, percent by volume
3/8	6 to 10
1/2	5 to 9
3/4	4 to 8
1	3.5 to 6.5
1 1/2	3 to 6
2	2.5 to 5.5
3	1.5 to 4.5

Figure A.1 Text, continued

4.6.2 – Concrete that is intended to be watertight shall conform to the following:

4.6.2.1 – For concrete made with normal weight
260 aggregate, water-cement ratio shall not exceed
261 0.50 by weight for exposure to fresh water and
0.45 by weight for exposure to seawater.

270 **4.6.2.2** – For concrete made with lightweight
271 aggregate, specified compressive strength f'_c
shall be at least 3750 psi for exposure to fresh
water and 4000 psi for exposure to seawater.

4.6.3 – Concrete that will be exposed to injurious
282 concentrations of sulfate-containing solutions
shall be made with sulfate-resisting cement, and
in addition:

280 **4.6.3.1** – For concrete made with normal weight
aggregate, water-cement ratio shall not exceed
0.50 by weight.

281 **4.6.3.2** – For concrete made with lightweight
aggregate, specified compressive strength f'_c
shall be at least 3750 psi.

4.7 – Average strength reduction

After sufficient test data become available from
the job, methods of "Recommended Practice for
Evaluation of Compression Test Results of
290 Concrete (ACI 214-65)" may be used to reduce the
amount by which the average strength must exceed f'_c below that indicated in Section 4.3.1
provided:

(a) Probable frequency of strength tests more than 500 psi below f'_c will not exceed 1 in 100,

(b) Probable frequency of an average of three consecutive strength tests below f'_c will not exceed 1 in 100, and

(c) Special exposure requirements of Section 4.6 are met.

4.8 – Evaluation and acceptance of concrete

300 **4.8.1 – Frequency of testing**

4.8.1.1 – Samples for strength tests of each class of concrete placed each day shall be taken not less than once a day, nor less than once for each 150 cu yd of concrete, nor less than once for each 5000 sq ft of surface area for slabs or walls.

4.8.1.2 – On a given project, if total volume of concrete is such that frequency of testing required by Section 4.8.1.1 would provide less than five strength tests for a given class of concrete, tests shall be made from at least five randomly selected batches or from each batch if fewer than five batches are used.

4.8.1.3 – When total quantity of a given class of concrete is less than 50 cu yd, strength tests may be waived by the Building Official, if in his judgment adequate evidence of satisfactory strength is provided.

4.8.1.4 – Average strength of two cylinders from the same sample, tested at 28 days or the specified earlier age, is required for each strength test.

4.8.2 – Tests of laboratory-cured specimens

4.8.2.1 – Samples for strength tests shall be taken
in accordance with "Method of Sampling Fresh 330
Concrete" (ASTM C 172).

4.8.2.2 – Cylinders for strength tests shall be
molded and laboratory-cured in accordance with
"Method of Making and Curing Concrete Test 340
Specimens in the Field" (ASTM C 31) and tested in 350
accordance with "Method of Test for Compressive Strength of Cylindrical Concrete Specimens" (ASTM C 39).

4.8.2.3 – Strength level of an individual class of concrete shall be considered satisfactory if both of the following requirements are met:

(a) The average of all sets of three consecutive 370
strength tests equal or exceed required f'_c.

(b) No individual strength test (average of two cylinders) falls below required f'_c by more than 500 psi.

4.8.2.4 – If either of the requirements of Section 380
4.8.2.3 are not met, steps shall be taken immediately to increase the average of subsequent strength test results. Additionally, requirements of Section 4.8.4 shall be observed if the requirement of Section 4.8.2.3(b) is not met.

4.8.3 – Tests of field-cured specimens

4.8.3.1 – The Building Official may require strength tests of cylinders cured under field conditions to check adequacy of curing and
protection of concrete in the structure. 420

4.8.3.2 – Field-cured cylinders shall be cured under field conditions in accordance with Section 7.4 of "Method of Making and Curing Concrete Test Specimens in the Field" (ASTM C 31).

4.8.3.3 – Field-cured test cylinders shall be molded at the same time and from the same samples as laboratory-cured test cylinders.

4.8.3.4 – Procedures for protecting and curing concrete shall be improved when strength of field-cured cylinders at the test age designated for measuring f'_c is less than 85 percent of that of companion laboratory-cured cylinders. When

Figure A.1 Text, continued.

laboratory-cured cylinder strengths are appreciably higher than f'_c, field-cured cylinder strengths need not exceed f'_c by more than 500 psi even though the 85 percent criterion is not met.

4.8.4 – Investigation of low-strength test results

381 **4.8.4.1** – If any strength test (Section 4.8.1.4) of laboratory-cured cylinders falls below required f'_c by more than 500 psi [Section 4.8.2.3(b)] or if tests of field-cured cylinders indicate deficiencies in protection and curing, steps shall be taken to assure that load-carrying capacity of the structure is not jeopardized.

400 **4.8.4.2** – If the likelihood of low-strength concrete is confirmed and computations indicate that load-carrying capacity may have been significantly reduced, tests of cores drilled from the area in question may be required in accordance with "Method of Obtaining and Testing Drilled Cores and Sawed Beams of Concrete" (ASTM C 42). In such case, three cores shall be taken for each strength test more than 500 psi below required f'_c.

4.8.4.3 – If concrete in the structure will be dry under service conditions, cores shall be air dried (temperature 60 to 80 F, relative humidity less than 60 percent) for 7 days before test and shall be tested dry. If concrete in the structure will be more than superficially wet under service conditions, cores shall be immersed in water for at least 48 hr and be tested wet. 400

4.8.4.4 – Concrete in an area represented by core tests shall be considered structurally adequate if the average of three cores is equal to at least 85 percent of f'_c and if no single core is less than 75 percent of f'_c. To check testing accuracy, locations represented by erratic core strengths may be retested.

4.8.4.5 – If criteria of Section 4.8.4.4 are not met, and if structural adequacy remains in doubt, the responsible authority may order load tests as outlined in Chapter 20 for the questionable portion of the structure, or take other action appropriate to the circumstances. 410

Figure A.1 Text, concluded.

```
REFE    NAME    SECT    PAGE    VALU    SOUR    TYPE    STAT    UTIL
   1    RSTA    S413     13     BOOL    DERI    TABL    CLAS    REQU
TITLE : STRNTH TESTS SHALL BE CONDUCTED AT SPECIFIED AGE
INGREDIENTS:1000 1010
ARGUMENT:   14   65
EQUIVALENTS :
COMMENT:
...........................................................
REFE    NAME    SECT    PAGE    VALU    SOUR    TYPE    STAT    UTIL
  10    SCSD    S414     13     BOOL    DERI            CLAS    REQU
TITLE : REQ FOR SPEC OF CONCRETE STRNTH ON DES DRAWING
INGREDIENTS:1500
ARGUMENT:   59   74
EQUIVALENTS :
COMMENT:
...........................................................
REFE    NAME    SECT    PAGE    VALU    SOUR    TYPE    STAT    UTIL
  20    FCT     S415     13     BOOL    DERI    TABL    CLAS    REQU
TITLE : REQ EST VAL OF F(CT) CORRES TO SPEC VAL OF F'C
INGREDIENTS:1020 1030
ARGUMENT:   15   74
EQUIVALENTS :
COMMENT:
...........................................................
REFE    NAME    SECT    PAGE    VALU    SOUR    TYPE    STAT    UTIL
  30    STS     S416     13     BOOL    DERI            CLAS    REQU
TITLE : REQ NOT ACC CONC ON BASIS OF SPLIT TENSILE STRNTH
INGREDIENTS:1510
ARGUMENT:   15   74
EQUIVALENTS :
COMMENT:
...........................................................
REFE    NAME    SECT    PAGE    VALU    SOUR    TYPE    STAT    UTIL
  40    WCC     S421     13     BOOL    DERI            CLAS    REQU
TITLE : REQ TO PROP FOR ADEQ WORKABILITY & CONSISTENCY
INGREDIENTS:1520
ARGUMENT:   09   06
EQUIVALENTS :
COMMENT:
...........................................................
REFE    NAME    SECT    PAGE    VALU    SOUR    TYPE    STAT    UTIL
  60    DATS    S431     13     NUME    DERI    TABL    CLAS    DETE
TITLE : DET OF REQUIRED AVG TEST STRNTH BY FIELD EXP
INGREDIENTS:1040 70
ARGUMENT:   04   06
EQUIVALENTS :
COMMENT:
```

Figure A.2 SASE-generated listing of derived data items for a standard for concrete quality.

```
REFE    NAME    SECT    PAGE    VALU    SOUR    TYPE    STAT    UTIL
  70    ARG4    S432      13    NUME    DERI    TABL     CLAS   DETE
TITLE : DET OF STD DEV OF STRENGTH TEST DATA
INGREDIENTS:1050 1290 1300
ARGUMENT:    04   06
EQUIVALENTS :
COMMENT:
.............................................................
REFE    NAME    SECT    PAGE    VALU    SOUR    TYPE    STAT    UTIL
 181            S444            BOOL    DERI            CLAS    REQU
TITLE : REQ THAT LTB W/C RAT YIELDS AVG TEST STR IN 60
INGREDIENTS:182  60
ARGUMENT:    06   63
EQUIVALENTS :
COMMENT: REQUIREMENT THAT LTB WATER-CEMENT RATIO YIELDS AVG T
        EST STIPULATED IN DATUM 60
.............................................................
REFE    NAME    SECT    PAGE    VALU    SOUR    TYPE    STAT    UTIL
 182            S444            NUME    DERI    TABL    CLAS    DETE
TITLE : DET OF STR CORR TO W/C RATIO OF LTB
INGREDIENTS:1060 1070 1080 1090 60
ARGUMENT:    06   63
EQUIVALENTS :
COMMENT: DETERMINATION OF STRENGTH CORRESPONDING TO WATER-CEM
        ENT RATIO OF LAB-TRIAL BATCH
.............................................................
REFE    NAME    SECT    PAGE    VALU    SOUR    TYPE    STAT    UTIL
 200    CEMT    S461      14    BOOL    DERI    TABL    CLAS    REQU
TITLE : REQ FOR MAX PERMISSIBLE W/C RATIO BY TABLE 4.5
INGREDIENTS:1100 1110 1120 1130
ARGUMENT:    06   63
EQUIVALENTS :
COMMENT:
.............................................................
REFE    NAME    SECT    PAGE    VALU    SOUR    TYPE    STAT    UTIL
 230    ENAC    S461      14    BOOL    DERI            CLAS    REQU
TITLE : CONC EXPOSED TO FREEZ  AIR CONT PER TBL 4.6.1
INGREDIENTS:1530 1540
ARGUMENT:    11   70
EQUIVALENTS :
COMMENT: CONCRETE EXPOSED TO FREEZING WHEN WET SHALL HAVE AN
        AIR CONTENT IN ACCORD WITH TABLE 4.6.1.
```

Figure A.2 SASE-generated listing of derived data items, continued.

```
REFE   NAME   SECT   PAGE   VALU   SOUR   TYPE   STAT   UTIL
 240   CEFT   S461     14   BOOL   DERI          CLAS   REQU
TITLE : CONC EXP TO FREEZ-MADE OF LT WT AGG-F'C>=3000PSI
INGREDIENTS:1120 1530 1550
ARGUMENT:    11   70
EQUIVALENTS :
COMMENT: CONCRETE EXPOSED TO FREEZING WHEN WET & MADE OF LIGH
        T WEIGHT AGGREGATE SHALL HAVE F'C <= 3000 PSI
.............................................................
REFE   NAME   SECT   PAGE   VALU   SOUR   TYPE   STAT   UTIL
 250   RCEF   S461     14   BOOL   DERI          CLAS   REQU
TITLE : CONC EXP FREEZ-NORM WT AGG-W/C RATIO > 0.83
INGREDIENTS:1530 1120 1560
ARGUMENT:    11   70
EQUIVALENTS :
COMMENT: CONCRETE EXPOSED TO FREEZING WHEN WET AND MADE OF NO
        RMAL WEIGHT AGGREGATE SHALL HAVE A W/C RATIO NOT EXCE
        EDING .83
.............................................................
REFE   NAME   SECT   PAGE   VALU   SOUR   TYPE   STAT   UTIL
 260   FRWA   S462     15   BOOL   DERI          CLAS   REQU
TITLE : CONC NORM WT AGG EXPOSED FRESH H2O-W/C RATIO<0.5
INGREDIENTS:1120 1570 1580 1560
ARGUMENT:    13   70
EQUIVALENTS :
COMMENT: CONCRETE OF NORMAL WEIGHT AGGREGATE EXPOSED TO FRESH
        WATER AND INTENDED TO BE WATER TIGHT SHALL HAVE A W/C
        RATIO < .5
.............................................................
REFE   NAME   SECT   PAGE   VALU   SOUR   TYPE   STAT   UTIL
 261   SEWA   S462     15   BOOL   DERI          CLAS   REQU
TITLE : CONC NORM WT AGG EXPOSED SEA H2O-W/C RATIO<=0.45
INGREDIENTS:1120 1570 1580 1560
ARGUMENT:    13   70
EQUIVALENTS :
COMMENT: CONCRETE OF NORMAL WEIGHT AGGREGATE EXPOSED TO SEA W
        ATER AND INTENDED TO BE WATERTIGHT SHALL HAVE A W/C R
        ATIO <= .45
.............................................................
REFE   NAME   SECT   PAGE   VALU   SOUR   TYPE   STAT   UTIL
 270   WTCF   S462     15   BOOL   DERI          CLAS   REQU
TITLE : CONC LT WT AGG EXPOSED FRESH H2O-F'C >= 3750PSI
INGREDIENTS:1120 1550 1570 1580
ARGUMENT:    13   70
EQUIVALENTS :
COMMENT: CONCRETE OF LIGHT WEIGHT AGGREGATE EXPOSED TO FRESH
        WATER INTENDED TO BE WATERTIGHT SHALL HAVE F'C >= 37
        50 PSI
```

Figure A.2 SASE-generated listing of derived data items, continued.

```
REFE    NAME    SECT    PAGE    VALU    SOUR    TYPE    STAT    UTIL
 271    WTCS    S462     15     BOOL    DERI            CLAS    REQU
TITLE : CONC LT WT AGG EXPOSED SEA H2O-F'C >=4000 PSI
INGREDIENTS:1120 1550 1570 1580
ARGUMENT:    13   70
EQUIVALENTS :
COMMENT: CONCRETE OF LIGHT WEIGHT AGGREGATE EXPOSED TO SEA WA
         TER AND INTENDED TO BE WATERTIGHT SHALL HAVE F'C >= 4
         000 PSI
.............................................................
REFE    NAME    SECT    PAGE    VALU    SOUR    TYPE    STAT    UTIL
 280    SER1    S463     15     BOOL    DERI            CLAS    REQU
TITLE : CONC NORM WT AGG EXPOS TO SULFATE-W/C RATIO<=0.5
INGREDIENTS:1590 1120 1560
ARGUMENT:    39   70
EQUIVALENTS :
COMMENT: CONCRETE MADE OF NORMAL WEIGHT AGGREGATE AND EXPOSED
         TO SULFATE SHALL HAVE A W/C RATIO <= .5
.............................................................
REFE    NAME    SECT    PAGE    VALU    SOUR    TYPE    STAT    UTIL
 281    SER2    S463     15     BOOL    DERI            CLAS    REQU
TITLE : CONC LT WT AGG EXPOSED TO SULFATE-F'C >=3750 PSI
INGREDIENTS:1120 1550 1590
ARGUMENT:    39   70
EQUIVALENTS :
COMMENT: CONCRETE MADE OF LIGHT WEIGHT AGGREGATE AND EXPOSED
         TO SULFATE SHALL HAVE F'C >= 3750 PSI
.............................................................
REFE    NAME    SECT    PAGE    VALU    SOUR    TYPE    STAT    UTIL
 282    SER3    S463     15     BOOL    DERI            CLAS    REQU
TITLE : CONC EXPOSED INJ SULFATE MADE W. SULFATE-RES CEM
INGREDIENTS:1590 1110
ARGUMENT:    39   70
EQUIVALENTS :
COMMENT: CONCRETE EXPOSED TO INJURIOUS CONCENTRATIONS OF SULF
         ATE CONTAINING SOLUTIONS SHALL BE MADE WITH SULFATE-R
         ISTING CEMENT
.............................................................
REFE    NAME    SECT    PAGE    VALU    SOUR    TYPE    STAT    UTIL
 290    AASR    S47      15     BOOL    DERI    TABL    CLAS    REQU
TITLE : REQ FOR PERMIS REDUCTN IN REQ'D AVG TEST STRNGTH
INGREDIENTS:1140 1150 1160 1250 1251
ARGUMENT:    04   06
EQUIVALENTS :
COMMENT:
```

Figure A.2 SASE-generated listing of derived data items, continued.

```
REFE   NAME   SECT   PAGE   VALU   SOUR   TYPE   STAT   UTIL
 300   STS    S481    15    BOOL   DERI   TABL   CLAS   REQU
TITLE : SAMPLE STR TESTS FOR EACH CLASS OF CONC REQ FREQ
INGREDIENTS:1170 1180 1190 1200 1210
ARGUMENT:   42   65   41
EQUIVALENTS :
COMMENT: ENCOMPASSES SECTIONS 4.8.1.1 THROUGH 4.8.1.4
...............................................................
REFE   NAME   SECT   PAGE   VALU   SOUR   TYPE   STAT   UTIL
 330   SLCS   S482    15    BOOL   DERI          CLAS   REQU
TITLE : SAMPLES FOR STR TESTS TAKEN IN ACCORD ASTM C172
INGREDIENTS:1600
ARGUMENT:   43   41   65
EQUIVALENTS :
COMMENT:
...............................................................
REFE   NAME   SECT   PAGE   VALU   SOUR   TYPE   STAT   UTIL
 340   MSTS   S482    15    BOOL   DERI          CLAS   REQU
TITLE : CYL MOLDED & LAB CURED IN ACCORD WITH ASTM C31
INGREDIENTS:1610
ARGUMENT:   07   41   65
EQUIVALENTS :
COMMENT: CYLINDERS FOR STRENGTH TESTS OF LABORATORY CURED SPE
        CIMENS SHALL BE MOLDED AND LAB CURED IN ACCORD WITH A
        STM C31
...............................................................
REFE   NAME   SECT   PAGE   VALU   SOUR   TYPE   STAT   UTIL
 350   CCST   S482    15    BOOL   DERI          CLAS   REQU
TITLE : CYL STR TEST LAB CURED SPEC TESTED PER ASTM C39
INGREDIENTS:1090
ARGUMENT:   55   65
EQUIVALENTS :
COMMENT: CYLINDERS FOR STRENGTH TESTS OF LABORATORY CURED SPE
        CIMENS SHALL BE TESTED IN ACCORD WITH ASTM C39
...............................................................
REFE   NAME   SECT   PAGE   VALU   SOUR   TYPE   STAT   UTIL
 370   ASL    S482    15    BOOL   DERI   TABL   CLAS   REQU
TITLE : ACCEPT OF STR LEVELS BASED ON LAB-CURED CYL
INGREDIENTS:1140 1220 1250 1251 1550
ARGUMENT:   55   65
EQUIVALENTS :
COMMENT: PERTAINS ALSO TO SECTION 4.8.3.4
```

Figure A.2 SASE-generated listing of derived data items, continued.

```
REFE    NAME    SECT    PAGE    VALU    SOUR    TYPE    STAT    UTIL
 380    RA1     S482      15    BOOL    DERI            CLAS    REQU
TITLE : SOMEONE SHALL TAKE STEPS TO INCREASE STR OF CONC
INGREDIENTS:370
ARGUMENT:    48   65
EQUIVALENTS :
COMMENT:
.............................................................
REFE    NAME    SECT    PAGE    VALU    SOUR    TYPE    STAT    UTIL
 381    RA2     S484      15    BOOL    DERI            CLAS    REQU
TITLE : SOMEONE SHALL TAKE STEPS-LD CAP NOT JEOPARDIZED
INGREDIENTS:370  420
ARGUMENT:    48   65
EQUIVALENTS :
COMMENT: SOMEONE SHALL TAKE STEPS TO ASSURE THAT LOAD CARRYIN
        G CAPACITY IS NOT JEOPARDIZED IF 4.8.2.3(B) ISN'T MET
.............................................................
REFE    NAME    SECT    PAGE    VALU    SOUR    TYPE    STAT    UTIL
 400    SBCT    S484      15    BOOL    DERI    TABL    CLAS    REQU
TITLE : ACCEPT OF IN SITU STR BASED ON CORE TESTS
INGREDIENTS:1260 1270 1271 1280 1550
ARGUMENT:    52   53    65
EQUIVALENTS :
COMMENT: FROM SECTION 4.8.4.2 THROUGH 4.8.4.4
.............................................................
REFE    NAME    SECT    PAGE    VALU    SOUR    TYPE    STAT    UTIL
 410    LT      S484      16    BOOL    DERI            CLAS    REQU
TITLE : DEC BY BLDG OFFL TO ORDER LD TESTS OR OTHER REQ
INGREDIENTS:400  1620
ARGUMENT:    51   53    65
EQUIVALENTS :
COMMENT: IF STRUCTURAL ADEQUACY REMAINS IN DOUBT, DECISION BY
        BUILDING OFFICIAL TO ORDER LOAD TESTS OR TAKE OTHER A
        PPROPRIATE ACTIONS IS REQUIRED.
.............................................................
REFE    NAME    SECT    PAGE    VALU    SOUR    TYPE    STAT    UTIL
 420    PROC    S483      16            DERI    TABL    CLAS    REQU
TITLE : PROC FOR PROT & CURING CONC SHALL BE ADEQUATE
INGREDIENTS:1230 1240 1250 1310 1550
ARGUMENT:    51   53    65
EQUIVALENTS :
COMMENT: PROCEDURES FOR PROTECTING AND CURING CONCRETE IN THE
        STRUCTURE SHALL BE ADEQUATE
```

Figure A.2 SASE-generated listing of derived data items, concluded.

```
REFE   NAME   SOUR   TITL
1000   TCON   INPU   TYPE OF CONCRETE
....................................................................
REFE   NAME   SOUR   TITL
1010   AGE    INPU   TEST AGE
....................................................................
REFE   NAME   SOUR   TITL
1020   FCT    INPU   VALUE OF F(CT)
....................................................................
REFE   NAME   SOUR   TITL
1030   LABT   INPU   LAB TEST CONDUCT
....................................................................
REFE   NAME   SOUR   TITL
1040   STDV   INPU   STD DEVIATION OF STR TEST DATA
....................................................................
REFE   NAME   SOUR   TITL
1050   RDAT   INPU   REPRESENTIVENESS OF STRENGTH TEST DATA
....................................................................
REFE   NAME   SOUR   TITL
1060   LTBT   INPU   PREPARATION OF LTB TEST SPECIMENS
....................................................................
REFE   NAME   SOUR   TITL
1070   LTAI   INPU   LTB AIR CONTENT
....................................................................
REFE   NAME   SOUR   TITL
1080   LTSL   INPU   LTB SLUMP
....................................................................
REFE   NAME   SOUR   TITL
1090   LTBT   INPU   LTB TEST PROCEDURE
....................................................................
REFE   NAME   SOUR   TITL
1100   PPWC   INPU   PERMISSION TO BASE PROPORTIONS ON W/C RATIO
....................................................................
REFE   NAME   SOUR   TITL
1110   TCEM   INPU   TYPE OF CEMENT
....................................................................
REFE   NAME   SOUR   TITL
1120   TAGG   INPU   TYPE OF AGGREGATE
....................................................................
REFE   NAME   SOUR   TITL
1130   TADM   INPU   TYPE OF ADMIXTURE
....................................................................
REFE   NAME   SOUR   TITL
1140   QDAT   INPU   QUALITY OF TEST DATA PER ACI214-65
```

Figure A.3 SASE-generated listing of input data items for a standard for concrete quality.

```
REFE   NAME   SOUR   TITL
1150   P1TS   INPU   PROBABILITY (STRENGTH < F'C - 500)
.................................................................
REFE   NAME   SOUR   TITL
1160   P3TS   INPU   PROBABILITY (AVG OF 3 STRENGTH TESTS < F'C)
.................................................................
REFE   NAME   SOUR   TITL
1170   QUAN   INPU   TOTAL QUANTITY OF CONCRETE PLACED
.................................................................
REFE   NAME   SOUR   TITL
1180   APPR   INPU   BUILDING OFFICIALS APPROVAL OF STRENGTH
.................................................................
REFE   NAME   SOUR   TITL
1190   STSA   INPU   STRENGTH TEST SAMPLING
.................................................................
REFE   NAME   SOUR   TITL
1200   TSNU   INPU   NUMBER OF TESTS PER CLASS OF CONCRETE
.................................................................
REFE   NAME   SOUR   TITL
1210   BCHN   INPU   NUMBER OF BATCHES PER CLASS OF CONCRETE
.................................................................
REFE   NAME   SOUR   TITL
1220   LOTS   INPU   NUMBER OF TESTS < (F'C - 500)
.................................................................
REFE   NAME   SOUR   TITL
1230   RTFC   INPU   REQ FOR STRENGTH TEST OF FIELD CURED CYLINDE
.................................................................
REFE   NAME   SOUR   TITL
1240   MCFC   INPU   METHOD OF MOLDING AND CURING FIELD CURED CYL
.................................................................
REFE   NAME   SOUR   TITL
1250   TSLC   INPU   TEST STRENGTH OF LAB CURED CYLINDERS
.................................................................
REFE   NAME   SOUR   TITL
1251   ACST   INPU   AVG OF 3 CONSECUTIVE STR TESTS OF LAB CURED
.................................................................
REFE   NAME   SOUR   TITL
1260   MOTC   INPU   METHOD OF OBTAINING AND TESTING CORES
.................................................................
REFE   NAME   SOUR   TITL
1270   NUMC   INPU   NUMBER OF CORES PER LOW STRENGTH TEST
.................................................................
REFE   NAME   SOUR   TITL
1271   CTS    INPU   CORE TEST STRENGTH
.................................................................
REFE   NAME   SOUR   TITL
1280   CTSA   INPU   3 CORE TEST STRENGTH AVERAGE
```

Figure A.3 SASE-generated listing of input data items, continued.

```
REFE    NAME    SOUR    TITL
1290    PREV    INPU    PREVIOUSLY SPECIFIED F'C
......................................................................
REFE    NAME    SOUR    TITL
1300    BMP     INPU    BACKGROUND MATERIALS AND PROPORTIONING
......................................................................
REFE    NAME    SOUR    TITL
1310    TSFC    INPU    TEST STRENGTH OF FIELD-CURED CYLINDERS
......................................................................
REFE    NAME    SOUR    TITL
1500    SPFC    INPU    SPECIFICATION OF F'C ON DESIGN DRAWINGS
......................................................................
REFE    NAME    SOUR    TITL
1510    CFCT    INPU    CRITERIA FOR USE OF F(CT)
......................................................................
REFE    NAME    SOUR    TITL
1520    W&C     INPU    WORKABILITY AND CONSISTENCY
......................................................................
REFE    NAME    SOUR    TITL
1530    FRX     INPU    EXPOSURE TO FREEZING
......................................................................
REFE    NAME    SOUR    TITL
1540    AC      INPU    AIR CONTENT
......................................................................
REFE    NAME    SOUR    TITL
1550    VFC     INPU    VALUE OF SPECIFIED F'C
......................................................................
REFE    NAME    SOUR    TITL
1560    WCR     INPU    W/C RATIO
......................................................................
REFE    NAME    SOUR    TITL
1570    TWX     INPU    TYPE OF WATER EXPOSURE
......................................................................
REFE    NAME    SOUR    TITL
1580    INT     INPU    INTENTION FOR WATER TIGHTNESS
......................................................................
REFE    NAME    SOUR    TITL
1590    SX      INPU    SULFATE EXPOSURE
......................................................................
REFE    NAME    SOUR    TITL
1600            INPU    METHOD OF SAMPLING FRESH CONCRETE
......................................................................
REFE    NAME    SOUR    TITL
1610    MMCC    INPU    METH OF MAKING & CURING CONC TEST SPEC IN FI
......................................................................
REFE    NAME    SOUR    TITL
1620    MLTS    INPU    METH OF LOAD TESTING THE STRUCTURE (CHAP 20)
```

Figure A.3 SASE-generated listing of input data items, concluded.

```
COMPLETE GLOBAL INGREDIENCE NETWORK

EXTREME LEVEL FROM OUTPUT

     0   1   2   3   4

     1  STRNTH TESTS SHALL BE CONDUCTED AT SPECIFIED AGE
  :...1000  TYPE OF CONCRETE
  :...1010  TEST AGE

    10  REQ FOR SPEC OF CONCRETE STRNTH ON DES DRAWING
  :...1500  SPECIFICATION OF F'C ON DESIGN DRAWINGS

    20  REQ EST VAL OF F(CT) CORRES TO SPEC VAL OF F'C
  :...1020  VALUE OF F(CT)
  :...1030  LAB TEST CONDUCT

    30  REQ NOT ACC CONC ON BASIS OF SPLIT TENSILE STRTH
  :...1510  CRITERIA FOR USE OF F(CT)

    40  REQ TO PROP FOR ADEQ WORKABILITY & CONSISTENCY
  :...1520  WORKABILITY AND CONSISTENCY

   181  REQ THAT LTB W/C RAT YIELDS AVG TEST STR IN 60
  :....182  DET OF STR CORR TO W/C RATIO OF LTB
  :   :...1060  PREPARATION OF LTB TEST SPECIMENS
  :   :...1070  LTB AIR CONTENT
  :   :...1080  LTB SLUMP
  :   :...1090  LTB TEST PROCEDURE
  :   :.....60  DET OF REQUIRED AVG TEST STRNTH BY FIELD EXP
  :       :...1040  STD DEVIATION OF STR TEST DATA
  :       :.....70  DET OF STD DEV OF STRENGTH TEST DATA
  :           :...1050  REPRESENTATIVENESS OF STRENGTH TEST DATA
  :           :...1290  PREVIOUSLY SPECIFIED F'C
  :           :...1300  BACKGROUND MATERIALS AND PROPORTIONING
  :........-60* DET OF REQUIRED AVG TEST STRNTH BY FIELD EXP

   200  REQ FOR MAX PERMISSIBLE W/C RATIO BY TABLE 4.5
  :...1100  PERMISSION TO BASE PROPORTIONS ON W/C RATIO
  :...1110  TYPE OF CEMENT
  :...1120  TYPE OF AGGREGATE
  :...1130  TYPE OF ADMIXTURE
```

Figure A.4 SASE-generated global ingredience network for a standard for concrete quality. (See section A.3.3 for a discussion of the network nomenclature used here.)

```
EXTREME LEVEL FROM OUTPUT

     0   1   2   3   4

   230  CONC EXPOSED TO FREEZING AIR CONT PER TBL 4.6.1
  :...1530  EXPOSURE TO FREEZING
  :...1540  AIR CONTENT

   240  CONC EXP TO FREEZ-MADE OF LT WT AGG-F'C>=3000PSI
  :..-1120  TYPE OF AGGREGATE
  :..-1530  EXPOSURE TO FREEZING
  :.......1550  VALUE OF SPECIFIED F'C

   250  CONC EXP FREEZ-NORM WT AGG-W/C RATIO > 0.83
  :..-1530  EXPOSURE TO FREEZING
  :..-1120  TYPE OF AGGREGATE
  :...1560  W/C RATIO

   260  CONC NORM WT AGG EXPOSED FRESH H20-W/C RATIO<0.5
  :..-1120  TYPE OF AGGREGATE
  :...1570  TYPE OF WATER EXPOSURE
  :...1580  INTENTION FOR WATER TIGHTNESS
  :..-1560  W/C RATIO

   261  CONC NORM WT AGG EXPOSED SEA H20-W/C RATIO<0.45
  :..-1120  TYPE OF AGGREGATE
  :..-1570  TYPE OF WATER EXPOSURE
  :..-1580  INTENTION FOR WATER TIGHTNESS
  :..-1560  W/C RATIO

   270  CONC LT WT AGG EXPOSED FRESH H20-F'C >= 3750PSI
  :..-1120  TYPE OF AGGREGATE
  :......-1550  VALUS OF SPECIFIED F'C
  :..-1570  TYPE OF WATER EXPOSURE
  :..-1580  INTENTION FOR WATER TIGHTNESS

   271  CONC LT WT AGG EXPOSED SEA H20-F'C > 4000 PSI
  :..-1120  TYPE OF AGGREGATE
  :......-1550  VALUE OF SPECIFIED F'C
  :..-1570  TYPE OF WATER EXPOSURE
  :..-1580  INTENTION FOR WATER TIGHTNESS

   280  CONC NORM WT AGG EXPOS TO SULFATE-W/C RATIO<=0.5
  :...1590  SULFATE EXPOSURE
  :..-1120  TYPE OF AGGREGATE
  :..-1560  W/C RATIO
```

Figure A.4 SASE-generated global ingredience network, continued.

```
EXTREME LEVEL FROM OUTPUT

    0   1   2   3   4

   281  CONC LT WT AGG EXPOSED TO SULFATE-F'C > 3750 PSI
  :..-1120  TYPE OF AGGREGATE
  :......-1550  VALUE OF SPECIFIED F'C
  :..-1590  SULFATE EXPOSURE

   282  CONC EXPOSED INJ SULFATE MADE W. SULFATE-RES CEM
  :..-1590  SULFATE EXPOSURE
  :..-1110  TYPE OF CEMENT

   290  REQ FOR PERMIS REDUCTN IN REQ'D AVG TEST STRNGTH
  :.......1140  QUALITY OF TEST DATA PER ACI214-65
  :...1150  PROBABILITY (STRENGTH < F'C - 500)
  :...1160  PROBABILITY (AVG OF 3 STRENGTH TESTS < F'C)

   300  SAMPLE STR TESTS FOR EACH CLASS OF CONC REQ FREQ
  :...1170  TOTAL QUANTITY OF CONCRETE PLACED
  :...1180  BUILDING OFFICIALS APPROVAL OF STRENGTH
  :...1190  STRENGTH TEST SAMPLING
  :...1200  NUMBER OF TESTS PER CLASS OF CONCRETE
  :..-1210  NUMBER OF BATCHES PER CLASS OF CONCRETE

   330  SAMPLES FOR STR TESTS TAKEN IN ACCORD ASTM C172
  :...1600  METHOD OF SAMPLING FRESH CONCRETE

   340  CYL MOLDED & LAB CURED SPEC TESTED PER ASTM C31
  :...1610  METH OF MAKING & CURING CONC TEST SPEC IN FIELD

   350  CYL STR TEST LAB CURED SPEC TESTED PER ASTM C31
  :......-1090  LTB TEST PROCEDURE

   380  SOMEONE SHALL TAKE STEPS TO INCREASE STR OF CONC
  :....370  ACCEPT OF STR LEVELS BASED ON LAB-CURED CYL
      :..-1140  QUALITY OF TEST DATA PER ACI214-65
      :...1220  NUMBER OF TESTS < (F'C - 500)
      :...1250  TEST STRENGTH OF LAB CURED CYLINDERS
      :...1251  AVG OF 3 CONSECUTIVE STR TESTS OF LAB CURED CYL
      :..-1550  VALUE OF SPECIFIED F'C
```

Figure A.4 SASE-generated global ingredience network, continued.

```
 EXTREME LEVEL FROM OUTPUT

      0   1   2   3   4

    381  SOMEONE SHALL TAKE STEPS-LD CAP NOT JEOPARDIZED
   :...-370* ACCEPT OF STR LEVELS BASED ON LAB-CURED CYL
   :....420  PROC FOR PROT & CURING CONC SHALL BE ADEQUATE
       :...1230  REQ FOR STRENGTH TEST OF FIELD CURED CYLINDERS
       :...1240  METHOD OF MOLDING AND CURING FIELD CURED CYL
       :..-1250  TEST STRENGTH OF LAB CURED CYLINDERS
       :...1310  TEST STRENGTH OF FIELD-CURED CYLINDERS
       :..-1550  VALUE OF SPECIFIED F'C

    410  DEC BY BLDG OFFL TO ORDER LD TESTS OR OTHER REQ
   :....400  ACCEPT OF IN SITU STR BASED ON CORE TESTS
   :   :...1260  METHOD OF OBTAINING AND TESTING CORES
   :   :...1270  NUMBER OF CORES PER LOW STRENGTH TEST
   :   :...1271  CORE TEST STRENGTH
   :   :...1280  3 CORE TEST STRENGTH AVERAGE
   :   :..-1550  VALUE OF SPECIFIED F'C
   :...1620  METH OF LOAD TESTING THE STRUCTURE (CHAP 20)
```

Figure A.4 SASE-generated global ingredience network, concluded.

```
COMPLETE GLOBAL INGREDIENCE NETWORK

EXTREME LEVEL FROM OUTPUT

    0   1   2   3   4

   181  REQ THAT LTB W/C RAT YIELDS AVG TEST STR IN 60
  :
  :....182  DET OF STR CORR TO W/C RATIO OF LTB
  :    :
  :    :...1060  PREPARATION OF LTB TEST SPECIMENS
  :    :
  :    :...1070  LTB AIR CONTENT
  :    :
  :    :...1080  LTB SLUMP
  :    :
  :    :...1090  LTB TEST PROCEDURE
  :    :
  :    :.....60  DET OF REQUIRED AVG TEST STRNTH BY FIELD EXP
  :        :
  :        :...1040  STD DEVIATION OF STR TEST DATA
  :        :
  :        :.....70  DET OF STD DEV OF STRENGTH TEST DATA
  :            :
  :            :...1050  REPRESENTATIVENESS OF STRENGTH TEST DATA
  :            :
  :            :...1290  PREVIOUSLY SPECIFIED F'C
  :            :
  :            :...1300  BACKGROUND MATERIALS AND PROPORTIONING
  :
  :........-60* DET OF REQUIRED AVG TEST STRNTH BY FIELD EXP
```

Figure A.5 Segment of SASE-generated global ingredience network enlarged to illustrate discussion of network nomenclature in section A.3.3.

REFE	NAME	TYPE	PARE	TITL
2	STRT	ACT	74	STRENGTH

FOSTER:
COMMENT:

....

REFE	NAME	TYPE	PARE	TITL
3	DEST	ACT	59	DESIGN STRENGTH

FOSTER:
COMMENT:

....

REFE	NAME	TYPE	PARE	TITL
4	ATS	ACT	6	REQ AVERAGE TEST STRENGTH

FOSTER:
COMMENT:

....

REFE	NAME	TYPE	PARE	TITL
5	HOWS	ACT	59	SHOWN ON DRAWINGS

FOSTER:
COMMENT:

....

REFE	NAME	TYPE	PARE	TITL
6	PROP	ACT		PROPORTIONING

FOSTER:
COMMENT:

....

REFE	NAME	TYPE	PARE	TITL
7		ACT	60	MAKING AND CURING SPECIMENS

FOSTER:
COMMENT:

....

REFE	NAME	TYPE	PARE	TITL
8				STRENGTH TEST

FOSTER:
COMMENT:

....

REFE	NAME	TYPE	PARE	TITL
9	WOCO	ACT	74	WORKABILITY & CONSISTENCY

FOSTER:
COMMENT:

Figure A.6 SASE-generated classifier list for a standard for concrete quality.

```
REFE     NAME     TYPE     PARE     TITL
  11     RESF     ACT        70     RESISTANCE TO FREEZING

FOSTER:
COMMENT:
.......................................................................
REFE     NAME     TYPE     PARE     TITL
  13     H2O      ACT        70     WATERTIGHT CONCRETE

FOSTER:
COMMENT:
.......................................................................
REFE     NAME     TYPE     PARE     TITL
  14                                AGE OF TEST

FOSTER:
COMMENT:
.......................................................................
REFE     NAME     TYPE     PARE     TITL
  15              ACT         2     SPLITTING TENSILE STRENGTH

FOSTER:
COMMENT:
.......................................................................
REFE     NAME     TYPE     PARE     TITL
  16                                IN ACCORDANCE WITH ASTM C330

FOSTER:
COMMENT:
.......................................................................
REFE     NAME     TYPE     PARE     TITL
  17                                FIELD EXPERIENCE

FOSTER:
COMMENT:
.......................................................................
REFE     NAME     TYPE     PARE     TITL
  18                                PROPORTIONS

FOSTER:
COMMENT:
.......................................................................
REFE     NAME     TYPE     PARE     TITL
  19                                MINIMUM ACCEPTABLE VALUE

FOSTER:
COMMENT:
.......................................................................
```

Figure A.6 SASE-generated classifier list, continued.

```
REFE      NAME      TYPE      PARE      TITL
  21                ACT          4      STANDARD DEVIATION

FOSTER:
COMMENT:

.....................................................................
REFE      NAME      TYPE      PARE      TITL
  23                                    IN ACCORDANCE WITH ASTM C39

FOSTER:
COMMENT:

.....................................................................
REFE      NAME      TYPE      PARE      TITL
  26                                    LAB TRIAL BATCH

FOSTER:
COMMENT:

.....................................................................
REFE      NAME      TYPE      PARE      TITL
  32                                    ACCEPTABLE CEMENT TYPE

FOSTER:
COMMENT:

.....................................................................
REFE      NAME      TYPE      PARE      TITL
  33                                    NORMAL WEIGHT AGGREGATE

FOSTER:
COMMENT:

.....................................................................
REFE      NAME      TYPE      PARE      TITL
  35                                    ACCEPTABLE ENTRAINED AIR CON
                                        TENT
FOSTER:
COMMENT:

.....................................................................
REFE      NAME      TYPE      PARE      TITL
  36                                    MAXIMUM ALLOWABLE W/C RATIO

FOSTER:
COMMENT:

.....................................................................
REFE      NAME      TYPE      PARE      TITL
  37                                    MINIMUM DESIGN STRENGTH

FOSTER:
COMMENT:

.....................................................................
```

Figure A.6 SASE-generated classifier list, continued.

REFE	NAME	TYPE	PARE	TITL
38				LIGHTWEIGHT AGGREGATE

FOSTER:
COMMENT:

....

REFE	NAME	TYPE	PARE	TITL
39		ACT	70	SULFATE:RESISTING CONCRETE

FOSTER:
COMMENT:

....

REFE	NAME	TYPE	PARE	TITL
41		ACT	65	SAMPLES FOR STRENGTH TESTS

FOSTER:
COMMENT:

....

REFE	NAME	TYPE	PARE	TITL
42		ACT	41	FREQUENCY OF SAMPLING

FOSTER:
COMMENT:

....

REFE	NAME	TYPE	PARE	TITL
43		ACT	41	TAKING OF SAMPLES FOR STRENG TH TESTS

FOSTER:
COMMENT:

....

REFE	NAME	TYPE	PARE	TITL
44		ACT	72	LAB CURED TEST CYLINDERS

FOSTER:
COMMENT:

....

REFE	NAME	TYPE	PARE	TITL
45				TABLE 4.5

FOSTER:
COMMENT:

....

REFE	NAME	TYPE	PARE	TITL
46				IN ACCORDANCE WITH ASTM C31

FOSTER:
COMMENT:

....

Figure A.6 SASE-generated classifier list, continued.

```
REFE      NAME      TYPE      PARE      TITL
  47                                    ADEQUATE STRENGTH

FOSTER:
COMMENT:
.....................................................................
REFE      NAME      TYPE      PARE      TITL
  48                ACT         65      ACTION TAKEN IN VIEW OF SUBS
                                        TANDARD STRENGTH TES
FOSTER:
COMMENT:
.....................................................................
REFE      NAME      TYPE      PARE      TITL
  50                                    PROTECTION AND CURING

FOSTER:
COMMENT:
.....................................................................
REFE      NAME      TYPE      PARE      TITL
  51                ACT         53      ADEQUATE PROCEDURES

FOSTER:
COMMENT:
.....................................................................
REFE      NAME      TYPE      PARE      TITL
  52                ACT         53      STRENGTH OF CONCRETE

FOSTER:
COMMENT:
.....................................................................
REFE      NAME      TYPE      PARE      TITL
  53                ACT         65      STRENGTH OF EXISTING STRUCTU
                                        RE
FOSTER:
COMMENT:
.....................................................................
REFE      NAME      TYPE      PARE      TITL
  55                ACT         60      STRENGTH TESTS OF LAB-CURED
                                        CYLINDERS
FOSTER:
COMMENT:
.....................................................................
REFE      NAME      TYPE      PARE      TITL
  56                ACT         72      FIELD CURED TEST CYLINDERS

FOSTER:
COMMENT:
.....................................................................
```

Figure A.6 SASE-generated classifier list, continued.

```
REFE      NAME      TYPE      PARE      TITL
  59                ACT          2      COMPRESSION STRENGTH

FOSTER:
COMMENT:
.....................................................................
REFE      NAME      TYPE      PARE      TITL
  60                ACT         65      CYLINDERS

FOSTER:
COMMENT:
.....................................................................
REFE      NAME      TYPE      PARE      TITL
  61                ACT         53      CORES

FOSTER:
COMMENT:
.....................................................................
REFE      NAME      TYPE      PARE      TITL
  63                                    W/C RATIO

FOSTER:
COMMENT:
.....................................................................
REFE      NAME      TYPE      PARE      TITL
  65                                    EVALUATION & ACCEPTANCE OF C
                                        ONCRETE
FOSTER:
COMMENT:
.....................................................................
REFE      NAME      TYPE      PARE      TITL
  67                ACT         73      FIELD EXPERIENCE METHOD

FOSTER:
COMMENT:
.....................................................................
REFE      NAME      TYPE      PARE      TITL
  68                ACT         73      LTB METHOD

FOSTER:
COMMENT:
.....................................................................
REFE      NAME      TYPE      PARE      TITL
  69                ACT         73      W/C RATIO METHOD

FOSTER:
COMMENT:
.....................................................................
```

Figure A.6 SASE-generated classifier list, continued.

```
REFE      NAME      TYPE      PARE      TITL
  70                ACT          6      SPECIAL EXPOSURE REQUIREMENT
                                        S
FOSTER:
COMMENT:
.....................................................................
REFE      NAME      TYPE      PARE      TITL
  71                ACT          4      STRENGTH TEST DATA

FOSTER:
COMMENT:
.....................................................................
REFE      NAME      TYPE      PARE      TITL
  72                ACT         60      TYPES OF CYLINDERS

FOSTER:
COMMENT:
.....................................................................
REFE      NAME      TYPE      PARE      TITL
  73                ACT          6      METHODS OF PROPORTIONING

FOSTER:
COMMENT:
.....................................................................
REFE      NAME      TYPE      PARE      TITL
  74                                    GENERAL

FOSTER:
COMMENT:
.....................................................................
```

Figure A.6 SASE-generated classifier list, concluded.

CLASSIFIER		PROVISION		
2	STRENGTH			
3	DESIGN STRENGTH			
4	REQ AVERAGE TEST STRENGTH			
		60	TITL:	DET OF REQUIRED AVG TEST STRNTH BY FIELD EXP
		70	TITL:	DET OF STD DEV OF STRENGT H TEST DATA
		290	TITL:	REQ FOR PERMIS REDUCTN OF RED'D AVG TEST STRNGTH
5	SHOWN ON DRAWINGS			
6	PROPORTIONING			
		40	TITL:	REQ TO PROP FOR ADEQ WORK ABILITY & CONSISTENCY
		60	TITL:	DET OF REQUIRED AVG TEST STRENGTH BY FIELD EXP
		181	TITL:	REQ THAT LTB W/C RAT YIEL DS AVG TEST STR IN 60
		182	TITL:	DET OF STR CORR TO W/C RA TIO OF LTB
		200	TITL:	REQ FOR MAX PERMISSIBLE W /C RATIO BY TABLE 4.5
		290	TITL:	REQ FOR PERMIS REDUCTN OF REQ'D AVG TEST STRNGTH
7	MAKING AND CURING SPECIMENS			
		340	TITL:	CYL MOLDED & LAB CURED IN ACCORD WITH ASTM C31
8	STRENGTH TEST			
9	WORKABILITY & CONSISTENCY			
		40	TITL:	REQ TO PROP FOR ADEQ WORK ABILITY & CONSISTENCY
11	RESISTANCE TO FREEZING			
		230	TITL:	CONC EXPOSED TO FREEZ AIR CONT PER TBL 4.6.1
		240	TITL:	CONC EXP TO FREEZ-MADE OF LT WT AGG-F'C>3000PSI
		250	TITL:	CONC EXP FREEZ-NORM WT AG G-W/C RATIO > 0.83
13	WATERTIGHT CONCRETE			
		260	TITL:	CONC NORM WT AGG EXPOSED FRESH H20-W/C RATIO<0.5
		261	TITL:	CONC NORM WT AGG EXPOSED SEA H20-W/C RATIO<=0.45
		270	TITL:	CONC LT WT AGG EXPOSED FR ESH H20-F'C>3750PSI
		271	TITL:	CONC LT WT AGG EXPOSED SE A H20-F'C >=4000 PSI

Figure A.7 SASE-generated scopelist for a standard for concrete quality.

CLASSIFIER		PROVISION		
14	AGE OF TEST			
		01	TITL:	STRNTH TESTS SHALL BE CON DUCTED AT SPECIFIED AGE
15	SPLITTING TENSILE STRENGTH			
		20	TITL:	REQ EST VAL OF F(CT) CORR ES TO SPEC VAL OF F'C
16	IN ACCORDANCE WITH ASTM C330			
17	FIELD EXPERIENCE			
18	PROPORTIONS			
19	MINIMUM ACCEPTABLE VALUE			
21	STANDARD DEVIATION			
23	IN ACCORDANCE WITH ASTM C39			
26	LAB TRIAL BATCH			
32	ACCEPTABLE CEMENT TYPE			
33	NORMAL WEIGHT AGGREGATE			
35	ACCEPTABLE ENTRAINED AIR CONTENT			
36	MAXIMUM ALLOWABLE W/C RATIO			
37	MINIMUM DESIGN STRENGTH			
38	LIGHTWEIGHT AGGREGATE			
39	SULFATE RESISTING CONCRETE			
		280	TITL:	CONC NORM WT AGG EXPOS TO SULFATE-W/C RATIO<=0.5
		281	TITL:	CONC LT WT AGG EXPOSED TO SULFATE-F'C >=3750 PSI
		282	TITL:	CONC EXPOSED INJ SULFATE MADE W. SULFATE RES CEM
41	SAMPLES FOR STRENGTH TESTS			
		300	TITL:	SAMPLE STR TESTS FOR EACH CLASS OF CONC REQ FREQ
		330	TITL:	SAMPLES FOR STR TESTS TAK EN IN ACCORD ASTM C172
		340	TITL:	CYL MOLDED & LAB CURED IN ACCORD WITH ASTM C31
42	FREQUENCY OF SAMPLING			
		300	TITL:	SAMPLE STR TESTS FOR EACH CLASS OF CONC REQ FREQ
43	TAKING OF SAMPLES FOR STRENGTH TESTS			
		330	TITL:	SAMPLES FOR STR TESTS TAK EN IN ACCORD ASTM C172
44	LAB CURED TEST CYLINDERS			
45	TABLE 4.5			
46	IN ACCORDANCE WITH ASTM C31			
47	ADEQUATE STRENGTH			

Figure A.7 SASE-generated scopelist, continued.

```
CLASSIFIER                     PROVISION
----------                     ---------
 48   ACTION TAKEN IN VIEW OF SUBSTANDARD STRENGTH TES
                                380    TITL:    SOMEONE SHALL TAKE STEPS
                                                TO INCREASE STR OF CONC
                                381    TITL:    SOMEONE SHALL TAKE STEPS-
                                                LD CAP NOT JEOPARDIZED
 50   PROTECTION AND CURING
 51   ADEQUATE PROCEDURES
                                410    TITL;    DEC BY BLDG OFFL TO ORDER
                                                LD TESTS OR OTHER REQ
                                420    TITL:    PROC FOR PROT & CURING CO
                                                NC SHALL BE ADEQUATE
 52   STRENGTH OF CONCRETE
                                400    TITL:    ACCEPT OF IN SITU STR BAS
                                                ED ON CORE TESTS
 53   STRENGTH OF EXISTING STRUCTURE
                                400    TITL:    ACCEPT OF IN SITU STR BAS
                                                ED ON CORE TESTS
                                410    TITL:    DEC BY BLDG OFFL TO ORDER
                                                LD TESTS OR OTHER REQ
                                420    TITL:    PROC FOR PROT & CURING CO
                                                NC SHALL BE ADEQUATE
 55   STRENGTH TESTS OF LAB-CURED CYLINDERS
                                350    TITL:    CYL STR TEST LAB CURED SP
                                                EC TESTED PER ASTM C31
                                370    TITL:    ACCEPT OF STR LEVELS BASE
                                                D ON LAB-CURED CYL
 56   FIELD CURED TEST CYLINDERS
 59   COMPRESSION STRENGTH
                                10     TITL:    REQ FOR SPEC OF CONCRETE
                                                STRNTH ON DES DRAWING
 60   CYLINDERS
 61   CORES
 63   W/C RATIO
                                181    TITL:    REQ THAT LTB W/C RAT YIEL
                                                DS AVG TEST STR IN 60
                                182    TITL:    DET OF STR CORR TO W/C RA
                                                TIO OF LTB
                                200    TITL:    REQ FOR MAX PERMISSIBLE W
                                                /C RATIO BY TABLE 4.5
 65   EVALUATION & ACCEPTANCE OF CONCRETE
                                01     TITL:    STRNTH TESTS SHALL BE CON
                                                DUCTED AT SPECIFIED AGE
                                300    TITL:    SAMPLE STR TESTS FOR EACH
                                                CLASS OF CONC REQ FREQ
```

Figure A.7 SASE-generated scopelist, continued.

```
CLASSIFIER                    PROVISION
----------                    ---------
(65   EVALUATION & ACCEPTANCE OF CONCRETE)
                               330    TITL:    SAMPLES FOR STR TESTS TAK
                                               EN IN ACCORD ASTM C172
                               340    TITL:    CYL MOLDED & LAB CURED IN
                                               ACCORD WITH ASTM C31
                               350    TITL:    CYL STR TEST LAB CURED SP
                                               EC TESTED PER ASTM C31
                               370    TITL:    ACCEPT OF STR LEVELS BASE
                                               D ON LAB-CURED CYL
                               380    TITL:    SOMEONE SHALL TAKE STEPS
                                               TO INCREASE STR OF CONC
                               381    TITL:    SOMEONE SHALL TAKE STEPS-
                                               LD CAP NOT JEOPARDIZED
                               400    TITL:    ACCEPT OF IN SITU STR BAS
                                               ED ON CORE TESTS
                               410    TITL:    DEC BY BLDG OFFL TO ORDER
                                               LD TESTS OR OTHER REQ
                               420    TITL:    PROC FOR PROT & CURING CO
                                               NC SHALL BE ADEQUATE
 67   FIELD EXPERIENCE METHOD
 68   LTB METHOD
 69   W/C RATIO METHOD
 70   SPECIAL EXPOSURE REQUIREMENTS
                               230    TITL:    CONC EXPOSED TO FREEZ AIR
                                               CONT PER TBL 4.6.1
                               240    TITL:    CONC EXP TO FREEZ-MADE OF
                                               LT WT AGG-F'C>3000PSI
                               250    TITL:    CONC EXP FREEZ-NORM WT AG
                                               G-W/C RATIO > 0.83
                               260    TITL:    CONC NORM WT AGG EXPOSED
                                               FRESH H20-W/C RATIO<0.5
                               261    TITL:    CONC NORM WT AGG EXPOSED
                                               SEA H20-W/C RATIO<=0.45
                               270    TITL:    CONC LT WT AGG EXPOSED FR
                                               ESH H20-F'C>3750PSI
                               271    TITL:    CONC LT WT AGG EXPOSED SE
                                               A H20-F'C >=4000 PSI
                               280    TITL:    CONC NORM WT AGG EXPOS TO
                                               SULFATE-W/C RATIO<=0.5
                               281    TITL:    CONC LT WT AGG EXPOSED TO
                                               SULFATE-F'C >=3750 PSI
                               282    TITL:    CONC EXPOSED INJ SULFATE
                                               MADE W. SULFATE RES CEM
```

Figure A.7 SASE-generated scopelist, continued.

CLASSIFIER		PROVISION		
71	STRENGTH TEST DATA			
72	TYPES OF CYLINDERS			
73	METHOD OF PROPORTIONING			
74	GENERAL			
		10	TITL:	REQ FOR SPEC OF CONCRETE STRNTH ON DES DRAWING
		20	TITL:	REQ EST VAL OF F(CT) CORR ES TO SPEC VAL OF F'C
		30	TITL:	REQ NOT ACC CONC ON BASIS OF SPLIT TENSILE STRNTH

Figure A.7 SASE-generated scopelist, concluded.

```
 ACCEPTABLE CEMENT TYPE

REFE   TITL
 282   CONC EXP INJ SULFATE MADE W. SULFATE-RES CEM

.......................................................................
***********************************************************************
 ACTION TAKEN IN VIEW OF SUBSTANDARD STRENGTH TES

REFE   TITL
 380   SOMEONE SHALL TAKE STEPS TO INCREASE STR OF CONC

.......................................................................
REFE   TITL
 381   SOMEONE SHALL TAKE STEPS-LD CAP NOT JEOPARDIZED

.......................................................................
***********************************************************************
 ADEQUATE PROCEDURES

REFE   TITL
 410   DEC BY BLDG OFFL TO ORDER LD TESTS OR OTHER REQ

.......................................................................
REFE   TITL
 420   PROC FOR PROT & CURING CONC SHALL BE ADEQUATE

.......................................................................
***********************************************************************
 ADEQUATE STRENGTH

***********************************************************************
 AGE OF TEST

REFE   TITL
  01   STRNTH TESTS SHALL BE CONDUCTED AT SPECIFIED AGE

.......................................................................
***********************************************************************
 COMPRESSION STRENGTH

REFE   TITL
  10   REQ FOR SPEC OF CONCRETE STRNTH ON DESIGN DRAWING

.......................................................................
```

Figure A.8 SASE-generated index for a standard for concrete quality.

```
CORES

**************************************************************************
CYLINDERS

**************************************************************************
DESIGN STRENGTH

**************************************************************************
EVALUATION & ACCEPTANCE OF CONCRETE

REFE   TITL
  01   STRNTH TESTS SHALL BE CONDUCTED AT SPECIFIED AGE

..........................................................................
REFE   TITL
 300   SAMPLE STR TESTS FOR EACH CLASS OF CONC REQ

..........................................................................
REFE   TITL
 330   SAMPLES FOR STR TESTS TAKEN IN ACCORD ASTM C172

..........................................................................
REFE   TITL
 340   CYL MOLDED & LAB CURED IN ACCORD WITH ASTM C31

..........................................................................
REFE   TITL
 350   CYL STR TEST LAB CURED SPEC TESTED PER ASTM C39

..........................................................................
REFE   TITL
 370   ACCEPT OF STR LEVELS BASED ON LAB-CURED CYL

..........................................................................
REFE   TITL
 380   SOMEONE SHALL TAKE STEPS TO INCREASE STR OF CONC

..........................................................................
REFE   TITL
 381   SOMEONE SHALL TAKE STEPS-LD CAP NOT JEOPARDIZED

..........................................................................
REFE   TITL
 400   ACCEPT OF IN SITU STR BASED ON CORE TESTS

..........................................................................
```

Figure A.8 SASE-generated index, continued.

```
(EVALUATION & ACCEPTANCE OF CONCRETE)

REFE   TITL
 410   DEC BY BLDG OFFL TO ORDER LD TESTS OR OTHER REQ

...........................................................................
REFE   TITL
 420   PROC FOR PROT & CURING CONC SHALL BE ADEQUATE

...........................................................................
***************************************************************************
 FIELD CURED TEST CYLINDERS

***************************************************************************
 FIELD EXPERIENCE

***************************************************************************
 FIELD EXPERIENCE METHOD

***************************************************************************
 FREQUENCY OF SAMPLING

REFE   TITL
 300   SAMPLE STR TESTS FOR EACH CLASS OF CONC REQ FREQ

...........................................................................
***************************************************************************
 GENERAL

REFE   TITL
  10   REQ FOR SPEC OF CONCRETE STRNTH ON DES DRAWING

...........................................................................
REFE   TITL
  20   REQ EST VAL OF F(CT) CORRES TO SPEC VAL OF F'C

...........................................................................
REFE   TITL
  30   REQ NOT ACC CONC ON BASIS OF SPLIT TENSILE STRNTH

...........................................................................
***************************************************************************
 IN ACCORDANCE WITH ASTM C31

***************************************************************************
 IN ACCORDANCE WITH ASTM C330

***************************************************************************
```

Figure A.8 SASE-generated index, continued.

```
 IN ACCORDANCE WITH ASTM C39

***********************************************************************
 LAB CURED TEST CYLINDERS

***********************************************************************
 LAB TRIAL BATCH

***********************************************************************
 LIGHTWEIGHT AGGREGATE

***********************************************************************
 LTB METHOD

***********************************************************************
 MAKING AND CURING SPECIMENS

REFE   TITL
 340   CYL MOLDED & LAB CURED IN ACCORD WITH ASTM C31

.......................................................................
***********************************************************************
 MAXIMUM ALLOWABLE W/C RATIO

***********************************************************************
 METHOD OF PROPORTIONING

***********************************************************************
 MINIMUM ACCEPTABLE VALUE

***********************************************************************
 MINIMUM DESIGN STRENGTH

***********************************************************************
 NORMAL WEIGHT CONCRETE

***********************************************************************
 PROPORTIONING

REFE   TITL
  40   REQ TO DROP FOR ADEQ WORKABILITY & CONSISTENCY

.......................................................................
REFE   TITL
  60   DET OF REQUIRED AVG TEST STRENGH TEST DATA

.......................................................................
```

Figure A.8 SASE-generated index, continued.

```
(PROPORTIONING)

REFE   TITL
 181   REQ THAT LTB W/C RAT YIELD AVG TEST STR IN 60

......................................................................
REFE   TITL
 182   DET OF STR CORR TO W/C RATIO OF LTB

......................................................................
REFE   TITL
 200   REQ FOR MAX PERMISSIBLE W/C RATIO BY TABLE 4.5

......................................................................
REFE   TITL
 290   REQ FOR PERMIS REDUCTN OF REQ'D AVG TEST STRNGTH

......................................................................
**********************************************************************
 PROPORTIONS

**********************************************************************
 PROTECTION AND CURING

**********************************************************************
 REQ AVERAGE TEST STRENGTH

REFE   TITL
  60   DET OF REQUIRED AVG STRNTH BY FIELD EXP

......................................................................
REFE   TITL
  70   DET OF STD DEV OF STRENGTH TEST DATA

......................................................................
REFE   TITL
 290   REQ FOR PERMIS REDUCTN OF REQ'D AVG TEST STRNGTH

......................................................................
**********************************************************************
 RESISTANCE TO FREEZING

REFE   TITL
 230   CONC EXPOSED TO FREEZ AIR CONT PER TBL 4.6.1

......................................................................
```

Figure A.8 SASE-generated index, continued.

```
(RESISTANCE TO FREEZING)

REFE   TITL
 240   CONC EXP TO FREEZ-MADE OF LT WT AGG-F'C>3000

.................................................................
REFE   TITL
 250   CONC EXP FREEZ-NORM WT AGG-W/C RATIO > 0.83

.................................................................
*****************************************************************
 SAMPLES FOR STRENGTH TESTS

REFE   TITL
 300   SAMPLE STR TESTS FOR EACH CLASS OF CONC REQ FREQ

.................................................................
REFE   TITL
 330   SAMPLES FOR STR TESTS TAKEN IN ACCORD ASTM C172

.................................................................
REFE   TITL
 340   CYL MOLDED & LAB CURED IN ACCORD WITH ASTM C31

.................................................................
*****************************************************************
 SHOWN ON DRAWINGS

*****************************************************************
 SPECIAL EXPOSURE REQUIREMENTS

REFE   TITL
 230   CONC EXPOSED TO FREEZ AIR CONT PER TBL 4.6.1

.................................................................
REFE   TITL
 240   CONC EXP TO FREEZ-MADE OF LT WT AGG-F'C>3000

.................................................................
REFE   TITL
 250   CONC EXP FREEZ-NORM WT AGG-W/C RATIO > 0.83

.................................................................
REFE   TITL
 260   CONC NORM WT AGG EXPOSED FRESH H20-W/C RATIO<0.5

.................................................................
```

Figure A.8 SASE-generated index, continued.

```
(SPECIAL EXPOSURE REQUIREMENTS)

REFE   TITL
 261   CONC NORM WT AGG EXPOSED SEA H20-W/C RATIO<=0.45

.......................................................................
REFE   TITL
 270   CONC LT WT AGG EXPOSED FRESH H20-F'C>3750PSI

.......................................................................
REFE   TITL
 271   CONC LT WT AGG EXPOSED SEA H20-F'C >=4000 PSI

.......................................................................
REFE   TITL
 280   CONC NORM WT AGG EXPOSED TO SULFATE-W/C RATIO<=0.5

.......................................................................
REFE   TITL
 281   CONC LT WT AGG EXPOSED TO SULFATE-F'C >=3750 PSI

.......................................................................
REFE   TITL
 282   CONC EXPOSED INJ SULFATE MADE W. SULFATE RES CEM

.......................................................................
***********************************************************************
 SPLITTING TENSILE STRENGTH

REFE   TITL
  20   REQ EST VAL OF F(CT) CORRES TO SPEC VAL OF F'C

.......................................................................
REFE   TITL
  30   REQ NOT ACC CONC ON BASIS OF SPLIT TENSILE STRNTH

.......................................................................
***********************************************************************
 STANDARD DEVIATION

***********************************************************************
 STRENGTH

***********************************************************************
```

Figure A.8 SASE-generated index, continued.

```
 STRENGTH OF CONCRETE

REFE   TITL
 400   ACCEPT OF IN SITU STR BASED ON CORE TEST

.......................................................................
***********************************************************************
 STRENGTH OF EXISTING STRUCTURE

REFE   TITL
 400   ACCEPT OF IN SITU STR BASED ON CORE TEST

.......................................................................
REFE   TITL
 410   DEC BY BLDG OFFL TO ORDER LD TESTS OR OTHER REQ

.......................................................................
REFE   TITL
 420   PROC FOR PROT & CURING CONC SHALL BE ADEQUATE

.......................................................................
***********************************************************************
 STRENGTH TEST

***********************************************************************
 STRENGTH TEST DATA

***********************************************************************
 STRENGTH TESTS OF LAB-CURED CYLINDERS

REFE   TITL
 350   CYL STR TEST LAB CURED SPEC TESTED PER ASTM C39

.......................................................................
REFE   TITL
 370   ACCEPT OF STR LEVELS BASED ON LAB-CURED CYL

.......................................................................
***********************************************************************
 SULFATE RESISTING CONCRETE

REFE   TITL
 280   CONC NORM WT AGG EXPOS TO SULFATE-W/C RATIO<0.5

.......................................................................
```

Figure A.8 SASE-generated index, continued.

```
(SULFATE RESISTING CONCRETE)

REFE   TITL
 281   CONC LT WT AGG EXPOSED TO SULFATE-F'C >=3750 PSI

.......................................................................
REFE   TITL
 282   CONC EXPOSED INJ SULFATE MADE W. SULFATE RES CEM

.......................................................................
***********************************************************************
 TABLE 4.5

***********************************************************************
 TAKING OF SAMPLES FOR STRENGTH TESTS

REFE   TITL
 330   SAMPLES FOR STR TESTS TAKEN IN ACCORD ASTM C172

.......................................................................
***********************************************************************
 TYPES OF CYLINDERS

***********************************************************************
 WATERTIGHT CONCRETE

REFE   TITL
 260   CONC NORM WT AGG EXPOSED FRESH H20-W/C RATIO<0.5

.......................................................................
REFE   TITL
 261   NORM WT AGG EXPOSED SEA H20-W/C RATIO<=0.45

.......................................................................
REFE   TITL
 270   CONC LT WT AGG EXPOSED FRESH H20-F'C>3750PSI

.......................................................................
REFE   TITL
 271   CONC LT WT AGG EXPOSED SEA H20-F'C >=4000 PSI

.......................................................................
***********************************************************************
```

Figure A.8 SASE-generated outline, continued.

```
 WORKABILITY & CONSISTENCY

REFE   TITL
  40   REQ TO PROP FOR ADEQ WORKABILITY & CONSISTENCY

.......................................................................
***********************************************************************
 W/C RATIO

REFE   TITL
 181   REQ THAT LTB W/C RAT YIELDS AVG TEST STR IN 60

.......................................................................
REFE   TITL
 182   DET OF STR CORR TO W/C RATIO OF LTB

.......................................................................
REFE   TITL
 200   REQ FOR MAX PERMISSIBLE W/C RATIO BY TABLE 4.5

.......................................................................
***********************************************************************
 W/C RATIO METHOD

***********************************************************************
```

Figure A.8 SASE-generated index, concluded.

```
CLASSIFIER                 PROVISION
----------                 --------
  74   GENERAL
     59   COMPRESSION STRENGTH
                              10      TITL:   REQ FOR SPEC OF CONCRETE
                                              STRNTH ON DES DRAWING
     15   SPLITTING TENSILE STRENGTH
                              20      TITL:   REQ EST VAL OF F(CT) CORR
                                              ES TO SPEC VAL OF F'C
   6   PROPORTIONING
      9   WORKABILITY & CONSISTENCY
                              40      TITL:   REQ TO PROP FOR ADEQ WORK
                                              ABILITY & CONSISTENCY
      4   REQ AVERAGE TEST STRENGTH
                              60      TITL:   DET OF REQUIRED AVG STRNT
                                              H BY FIELD EXP
                              70      TITL:   DET OF STD DEV OF STRENGT
                                              H TEST DATA
                              290     TITL:   REQ FOR PERMIS REDUCTN OF
                                              REQ'D AVG TEST STRNGTH
     63   W/C RATIO
                              181     TITL:   REQ THAT LTB W/C RAT YIEL
                                              DS AVG TEST STR IN 60
                              182     TITL:   DET OF STR CORR TO W/C RA
                                              TIO OF LTB
                              200     TITL:   REQ FOR MAX PERMISSIBLE W
                                              /C RATIO BY TABLE 4.5
     70   SPECIAL EXPOSURE REQUIREMENTS
        11   RESISTANCE TO FREEZING
                              230     TITL:   CONC EXPOSED TO FREEZ AIR
                                              CONT PER TBL 4.6.1
                              240     TITL:   CONC EXP TO FREEZ-MADE OF
                                              LT WT AGG-F'C>3000
                              250     TITL:   CONC EXP FREEZ-NORM WT AG
                                              G-W/C RATIO > 0.83
        13   WATERTIGHT CONCRETE
                              260     TITL:   CONC NORM WT AGG EXPOSED
                                              FRESH H20-W/C RATIO<0.5
                              261     TITL:   CONC NORM WT AGG EXPOSED
                                              SEA H20-W/C RATIO<0.45
                              270     TITL:   CONC LT WT AGG EXPOSED FR
                                              ESH H20-F'C>3750PSI
                              271     TITL:   CONC LT WT AGG EXPOSED SE
                                              A H20-F'C > 4000 PSI
```

Figure A.9 SASE-generated outline for a standard for concrete quality.

```
CLASSIFIER                   PROVISION
----------                   ---------
  (6    PROPORTIONING)
    (70    SPECIAL EXPOSURE REQUIREMENTS)
       39     SULFATE RESISTING CONCRETE
                                 280     TITL:    CONC NORM WT AGG EXPOS TO
                                                  SULFATE-W/C RATIO<=0.5
                                 281     TITL:    CONC LT WT AGG EXPOSED TO
                                                  SULFATE-F'C > 3750 PSI
                                 282     TITL:    CONC EXPOSED INJ SULFATE
                                                  MADE W. SULFATE RES CEM
  65    EVALUATION & ACCEPTANCE OF CONCRETE
     41    SAMPLES FOR STRENGTH TESTS
       42     FREQUENCY OF SAMPLING
                                 300     TITL:    SAMPLE STR TESTS FOR EACH
                                                  CLASS OF CONC REQ FREQ
       43     TAKING OF SAMPLES FOR STRENGTH TESTS
                                 330     TITL:    SAMPLES FOR STR TESTS TAK
                                                  EN IN ACCORD ASTM C172
        7     MAKING AND CURING SPECIMENS
                                 340     TITL:    CYL MOLDED & LAB CURED IN
                                                  ACCORD WITH ASTM C31
     14    AGE OF TEST
                                 01      TITL:    STRNTH TESTS SHALL BE CON
                                                  DUCTED AT SPECIFIED AGE
     55    STRENGTH TESTS OF LAB-CURED CYLINDERS
                                 350     TITL:    CYL STR TEST LAB CURED SP
                                                  EC TESTED PER ASTM C31
                                 370     TITL:    ACCEPT OF STR LEVELS BASE
                                                  D ON LAB-CURED CYL
     48    ACTION TAKEN IN VIEW OF SUBSTANDARD STRENGTH TES
                                 380     TITL:    SOMEONE SHALL TAKE STEPS
                                                  TO INCREASE STR OF CONC
                                 381     TITL:    SOMEONE SHALL TAKE STEPS-
                                                   LD CAP NOT JEOPARDIZED
     53    STRENGTH OF EXISTING STRUCTURE
       51     ADEQUATE PROCEDURES
                                 410     TITL:    DEC BY BLDG OFFL TO ORDER
                                                  LD TESTS OR OTHER REQ
                                 420     TITL:    PROC FOR PROT & CURING CO
                                                  NC SHALL BE ADEQUATE
       52     STRENGTH OF CONCRETE
                                 400     TITL:    ACCEPT OF IN SITU STR BAS
                                                  ED ON CORE TEST
```

Figure A.9 SASE-generated outline, concluded.

Table A.1 Requirement for strength tests at specified age (datum 1)

	DECISION TABLE		1	2	3	E
1	HI-EARLY CONCRETE	*	T	F	F	
2	TEST AGE = 28 DAYS	*	.	T	F	
3	TEST AGE AS SPECIFIED	*	T	+	T	
1	REQ FOR TEST AGE = SAT.	*	X	X	X	
2	REQ = VIOLATED	*				X

ELSE: RUL	1	2	3
C 1	T	T	F
C 2	T	F	F
C 3	F	F	F

Table A.2 Requirement establishing the value of f_ct corresponding to specified value of f'_c (datum 20)

	DECISION TABLE		1	E
1	DESIGN CRIT PERMIT USE OF F(CT)	*	T	
2	LAB TESTS IN ACCORD WITH AST M C330	*	T	
1	REQ EST VAL OF F(CT) = SAT.	*	X	
2	REQ = VIOLATED	*		X

ELSE: RUL	1	2
C 1	T	F
C 2	T	.

Table A.3 Determination of required average test strength (datum 60)

	DECISION TABLE		1	2	3	4	5	6
1	STDEV < 300	*	T	-	-	-	-	-
2	300<= STDEV <400	*	-	T	-	-	-	-
3	400<= STDEV <500	*	-	-	T	-	-	-
4	500<= STDEV <600	*	-	-	-	T	-	-
5	STDEV > 600	*	-	-	-	-	T	-
6	STDEV NOT DEFINED	*	-	-	-	-	-	T
1	REQ AVG TEST STR = F'C+400	*	X					
2	REQ AVG TEST STR = F'C+550	*		X				
3	REQ AVG TEST STR = F'C+700	*			X			
4	REQ AVG TEST STR = F'C+900	*				X		
5	REQ AVG TEST STR = F'C+1200	*					X	X

ELSE: RUL	1
C 1	F
C 2	F
C 3	F
C 4	F
C 5	F
C 6	F

Table A.4 Determination of standard deviation of strength test data (datum 70)

	DECISION TABLE		1	2	E
1	DATA REPRESENTS >= 30 CONSEC UTIVE TESTS	*	T	.	
2	DATA ARE STAT AVG OF 2 GROUP S TOT>= 30 TESTS	*	-	T	
3	BACKGROUND STR TESTS REP CON C PRODUCED FOR F'C(BT) SUCH THAT (F'C-1000)<=F'C(BT)<=(F 'C+1000)	*	T	T	
4	BACKGROUND MATERIALS & PROPO RTIONS ARE NOT MORE CLOSELY RESTRICTED THAT FOR PROPOSED WORK	*	T	T	
1	STDEV COMPUTED BY STATISTICS	*	X	X	
2	STDEV NOT DEFINED	*			X

E: RUL	1	2	3	4	5	6	7
C 1	T	T	T	T	F	F	F
C 2	T	T	F	F	T	T	F
C 3	T	F	T	F	T	F	.
C 4	F	.	F	.	F	.	.

Table A.5 Determination of strength corresponding to water-cement ratio of laboratory trial batch (datum 182)

	DECISION TABLE		1	E
1	CURVE BASED ON >=3 PTS REPG BATCHES W/STR +/- THAT GIVEN BY DATUM 60	*	T	
2	EACH PT BASED ON >= 3 CYLS M ADE PER ASTM C192 & TESTED P ER ASTM C39	*	T	
3	BATCH AIR = +/- 0.5% & TACH SLUMP = +/- 0.75 IN OF MAX A LLOWED	*	T	
1	STRENGTH GIVEN BY CURVE	*	X	
2	STRENGTH NOT DETERMINED	*		X

ELSE: RUL	1	2	3
C 1	T	T	F
C 2	T	F	.
C 3	F	.	.

Table A.6 Requirement for maximum permissible w/c ratio by table 4.5 (datum 200)

```
    DECISION TABLE                          1  E
-------------------------------------------------
 1  SUITABLE DATA NOT AVAILABLE      *  T
    FROM FIELD EXPERIENCE OR LTB     *
    AND PERMISSION GRANTED BY (?     *
    ) TO USE W/C RATIO LIMITS        *
 2  CEMENT IS TYPE I, IA, II, II     *  T
    A, III, IIIA, OR V PER ASTM      *
    C150, OR TYPE IS, IS-A, IS(M     *
    S), IS-A(MS), IP, IP-A, OR P     *
    , PER ASTM C595                  *
 3  CONCRETE CONTAINS LIGHTWEIGH     *  F
    T AGGREGATE                      *
 4  CONCRETE CONTAINS ADMIXTURE      *  F
    OTHER THAN ENTRAINED AIR         *
*************************************************
 1  REQ FOR MAX PERMISSIBLE W/C      *  X
    RATIO BY TABLE 4.5 = SAT.        *
 2  REQ                = VIOLATED    *     X
-------------------------------------------------
```

```
ELSE:  RUL    1  2  3  4
       ------------------
       C 1    T  T  T  F
       C 2    T  T  F  .
       C 3    T  F  .  .
       C 4    .  T  .  .
       ------------------
```

Table A.7 Requirement for permissible reduction of average test strength (datum 290)

```
    DECISION TABLE                          1  E
-------------------------------------------------
 1  TEST DATA MEETS ACI214-65        *  T
 2  PROB. [STR<F'C-500] < .01        *  T
 3  PROB. [(AVG OF 3 STR TESTS)<     *  T
    F'C] < .01                       *
*************************************************
 1  REQ FOR PERMIS REDUCT OF REQ     *  X
    'D AVG TEST STR (CF ACI214-      *
    65) = SATISFIED                  *
 2  REQ = VIOLATED                   *     X
-------------------------------------------------
```

```
ELSE:  RUL    1  2  3
       ---------------
       C 1    T  T  F
       C 2    T  F  .
       C 3    F  .  .
       ---------------
```

Table A.9 Requirement for the frequency of strength test samples taken for each class of concrete (datum 300)

	DECISION TABLE		1	2	3	E
1	TOTAL QUANTITY OF EACH CLASS	*	T	F	F	
	< 50 CYL & STR TEST WAIVED B	*				
	Y BLDG OFFL BASED ON EVIDENC	*				
	E OF SATISFACTORY STRENGTH	*				
2	CONC SAMPLED >= 1/DAY OF PLA	*	.	T	T	
	CEMENT	*				
3	CONC SAMPLED >=1/150 CYL	*	.	T	T	
4	CONC SAMPLED >= 1/5000 SF OF	*	.	T	T	
	SLAB OR FLOOR SURFACE	*				
5	PROVIDES >= 5 STR TESTS, EAC	*	.	T	F	
	H OF 2 CYLS/SAMPLE	*				
6	STR TESTS MADE FROM >= 5 RAN	*	.	.	T	
	DOMLY SELECTED BATCHES, OR F	*				
	ROM EACH BATCH IF BATCHES <5	*				
1	REQ FOR FREQ OF STR TEST SA	*	X	X	X	
	MPLES = SATISFIED	*				
2	REQ = VIOLATED	*				X

E: RUL	1	2	3	4
C 1	F	F	F	F
C 2	T	T	T	F
C 3	T	T	F	.
C 4	T	F	.	.
C 5	F	.	.	.
C 6	F	.	.	.

Table A.9 Requirement for strength levels based on lab-cured cylinders (datum 370)

	DECISION TABLE		1	E
1	AVG OF ALL SETS OF 3 CONSECU	*	T	
	TIVE STR TESTS >= F'C	*		
2	NO SINGLE TEST <[F'C-500]	*	T	
1	REQ FOR STR LEVELS = SAT.	*	X	
2	REQ = VIOLATED	*		X

ELSE: RUL	1	2
C 1	T	F
C 2	F	.

Table A.10 Acceptability of in-situ strength based on core tests (datum 400)

	DECISION TABLE		1	E
1	CORES OBTAINED AND TESTED P ER ASTM C42	* *	T	
2	THREE CORES PER LOW STR TEST	*	T	
3	AIR DRIED 7 DAYS & TESTED DR Y IF DRY IN SERVICE, OR IMME RSED 48 HRS AND TESTED WET I F WET IN SERVICE	* * * *	T	
4	[AVG OF 3 CORES]>=.85F'C AND NO CORE < .75F'C	* *	T	
******	******************************	*	***	***
1	STRUCTURAL ADEQUACY BY CORE TEST = SATISFIED	* *	X	
2	STRUCTURAL ADEQUACY BY CORE TEST = NOT SATISFIED	* *		X

ELSE: RUL	1	2	3	4
C 1	T	T	T	F
C 2	T	T	F	F
C 3	T	F	.	.
C 4	F	.	.	.

Table A.11 Requirement for the protection and curing of concrete (datum 420)

	DECISION TABLE		1	2	3	E
1	BLDG OFFL REQUIRES STR TEST OF FIELD CURED CYLINDERS	* *	F	T	T	
2	FIELD CURED CYLINDERS CURED BY SEC 7.4 OF ASTM C31	* *	.	T	T	
3	FIELD CURED CYLINDERS MOLDED AT SAME TIME AMD FROM SAME S AMPLES AS LAB CURED	* * *	.	T	T	
4	STR < .85 LAB CURED CYLS.	*	.	T	F	
5	STR >=F'C+500	*				
******	******************************	*	***	***	***	***
1	REQ FOR PROTECTION AND CURIN G OF CONC = SATISFIED	* *	X	X	X	
2	REQ = VIOLATED	*				X

ELSE: RUL	1	2	3
C 1	T	T	T
C 2	T	T	F
C 3	T	F	.
C 4	F	.	.
C 5	F	.	.

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APPENDIX B. ANNOTATED BIBLIOGRAPHY

The concepts presented in the report are the results of the work of several groups of researchers over the last 20 years. The most significant research reports and papers are presented below in chronological order, with brief explanatory comments. The reader should be warned that this work represents evolutionary growth in a new area; in particular, the terminology used has changed over the years.

[1] Fenves, S. J., "Tabular Decision Logic for Structural Design," Journal of the Structural Division, Vol. 92, No. ST6 (New York: American Society of Civil Engineers, 1966), pp. 473-490.

First discussion of the use of decision tables to represent provisions of design specifications.

[2] Fenves, S. J., Gaylord, E. H., Jr., and Goel, S. K., "Decision Table Formulation of the 1969 American Institute of Steel Construction Specification," Civil Engineering Studies, No. SRS 347 (Urbana: University of Illinois, 1969).

First major application of [1] to a design specification. Introduces the concept of "switching tables" to represent the organization or outline, "testing tables" for evaluating requirements, and "working tables" to evaluate determinations.

[3] Goel, S. K., and Fenves, S. J., "Computer-Aided Processing of Design Specifications," Journal of the Structural Division, Vol. 97, No. ST1 (New York: American Society of Civil Engineers, 1971), pp. 463-479.

Description of a program for execution of decision tables described in [2]. Introduces concept of "direct execution" and "condition execution".

[4] Wright, R. N., Boyer, L. T., and Melin, J. W., "Constraint Processing in Design," Journal of the Structural Division, Vol. 97, No. ST1 (New York: American Society of Civil Engineers, 1971), pp. 481-494.

Introduces distinction between criterion in a design specification and its application in a specific instance, termed "constraint".

[5] Seeberg, P., "Decision Table Formulation of the Specification for the Design of Cold-Formed Steel Structural Members" (Milwaukee: University of Wisconsin, 1971).

A major application patterned directly after [2].

[6] Fenves, S. J., "Representation of the Computer-Aided Design Process by a Network of Decision Tables," Computer and Structures, Vol. 3, No. 5 (New York: Pergamon Press, 1973), pp. 1099-1107.

Combination of concepts from [3] and [4], generalizing the process of conditional execution.

[7] Fenves, S. J., D. J. Nyman, and R. N. Wright, "Reformulation of the Decision Tables for the 1969 AISC Specification", Unpublished progress report (Urbana: University of Illinois, July, 1972).

Reformulated tables from [2], with each decision table producing one datum.

[8] Nyman, D. J., S. J. Fenves, and R. N. Wright, "Restructuring Study of the AISC Specification", Civil Engineering Studies, No. SRS 393 (Urbana: University of Illinois, 1973).

First study devoted exclusively to formulation and organization of a design specification. Introduces "functional network" and "organizational network"; three levels of analysis and organization, (subsequently named outline, information network, and decision tables).

[9] Nyman, D. J. and Fenves, S. J., "An Organization Model for Design Specifications," Journal of the Structural Division, Vol. 101, No. ST4 (New York: American Society of Civil Engineers, 1975), pp. 697-716.

Major extension of [8], introducing organization strategies for outlines and information network, exploring strategies for generating textual expressions.

[10] Noland, J. L. and Feng, C. C., "American Concrete Institute Building Code in Decision Logic Table Format," Journal of the Structural Division, Vol. 101, No. ST4 (New York: American Society of Civil Engineers, 1975), pp. 677-696.

A major application patterned after [2], but introducing a number of new concepts, including "active" design tables instead of "passive" testing tables for evaluating criteria.

[11] Harris, J. R., J. W. Melin, R. L. Tavis, and R. N. Wright, "Technology for the Formulation and Expression of Specifications, Volume I: Final Report," Civil Engineering Studies, No. SRS 423 (Urbana: University of Illinois, 1975).

Harris, J. R., J. W. Melin, R. L. Tavis, and R. N. Wright, "Technology for the Formulation and Expression of Specifications, Volume II: Program User's Manual," Civil Engineering Studies, No. SRS 424 (Urbana: University of Illinois, 1975).

Harris, J. R., J. W. Melin, R. L. Tavis, and R. N. Wright, "Technology for the Formulation and Expression of Specifications, Volume III: Technical Reference Manual," Civil Engineering Studies, No.

SRS 425 (Urbana: University of Illinois, 1975).

Documentation of methodology and program developed up to 1975. Tutorial material on decision tables, decision trees, and information networks used in chapters 4, 5, and 7.

[12] Wu, S. K. F. and D. W. Murray, "Decision Table Processing of the Canadian Standards Association Specification S16.1", Structural Engineering Report No. 52 (Edmonton, Canada: University of Alberta, 1976).

A major application patterned after [2] and [3], including a modified program for executing decision tables.

[13] Fenves, S. J., K. Rankin, and H. Tejuja, The Structure of Building Specifications, Building Science Series 90 (Washington: National Bureau of Standards, 1976).

Extension of previous studies to performance and prescriptive specifications. First general formulation of requirements.

[14] Fenves, S. J., and R. N. Wright, The Representation and Use of Design Specifications, Technical Note 940 (Washington: National Bureau of Standards, 1977).

A synthesis of previous studies, introducing strategies for analysis and synthesis, distinguishing between formulation, expression and use.

[15] Nyman, D. J., J. D. Mozer, and S. J. Fenves, "Decision Table Formulation of the Load and Resistance Factor Design Criteria," Report R-77-6, Department of Civil Engineering (Pittsburgh: Carnegie-Mellon University, 1977).

A major application patterned after [2] and [9].

[16] Cunningham, L. K., J. W. Melin, and R. L. Tavis, "Detailed Application of a Technology for the Formulation and Expression of Standards," Civil Engineering Studies No. SRS 446, (Urbana: University of Illinois, 1978).

A tutorial case study on a very detailed level of analysis.

[17] Harris, J. R., S. J. Fenves, and R. N. Wright, Analysis and Tentative Seismic Design Provisions for Buildings, NBS Technical Note 1100 (Washington: National Bureau of Standards, 1979).

The largest application to date.

[18] Fenves, S. J., "Recent Developments in the Methodology for the Formulation and Organization of Design Specifications," Int. J. of Engineering Structures, Vol. 1, No. 5 (London: IPC Science and

Technology Press, 1979) pp. 223-229.

A summary of [15].

[19] Rasdorf, W. J. and S. J. Fenves, "Representation and Analysis of Design Specifications at the Interface Between Outlines, Networks, and Decision Tables," Report R-127-879, Department of Civil Engineering (Pittsburgh: Carnegie-Mellon University, 1979).

Procedures for splitting, expanding and compressing decision tables and making corresponding changes in information network and outline.

[20] Harris, J. R. and R. N. Wright, _Organization of Building Standards_ Building Science Series 136 (Washington: National Bureau of Standards, 1981).

Major survey of previous work and classification schemes and criteria and methods for organizing specifications. Tutorial material on provisions, classifiers, organizations, and outlines extensively used in chapters 8 through 13.

[21] Fenves, S. J., "Software for Analysis of Standards," _Computing in Civil Engineering_ (New York: American Society of Civil Engineers, 1980).

Summary of specification for SASE program.

[22] Holtz, N. M. and S. J. Fenves, "Using Design Specifications for Design," _ibid_, pp. 92-101.

Extension of methodology to symbolically reformulate specifications presented in checking mode into constraints on design variables.

[23] Rasdorf, W. and S. J. Fenves, "Design Specification Representation and Analysis," _ibid_, pp. 102-111.

A summary of [19].

[24] Harris, J. R., "Organization of Design Standards," _ibid_, pp. 112-123.

A summary of [20].

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A summary of methods used in [17].

[26] Harris, J. R., S. J. Fenves, and R. N. Wright, "Logical Analysis of Tentative Seismic Provisions," _J. of the Structural Division_, Vol.

107, No. ST8 (New York: American Society of Civil Engineers, 1981), pp. 1629-1641.

A summary of findings from [17].

[27] Tavis, R. L. and J. W. Melin, "Use of Technical Analysis in Editing," Civil Engineering Studies No. SRS 473 (Urbana: University of Illinois, 1980).

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[28] Stirk, J. A., "Two Software Aids for Design Specification Use," Unpublished M.S. Thesis (Pittsburgh: Carnegie-Mellon University, 1981).

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[29] Fenves, S. J., "A Methodology for the Evaluation of Designs for Standards Conformance," Proceedings of IABSE Symposium on Informatics in Structural Engineering (Zurich: Int. Assoc. of Bridge and Str. Eng., 1983), pp. 301-316.

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[30] Howard, H. C. and S. J. Fenves, "Representation and Comparison of Design Specifications," Report R-83-141, Department of Civil Engineering (Pittsburgh: Carnegie-Mellon University, 1983).

Extension of previous work to the comparison and representation of similarities and differences between individual design specifications.

[31] Stahl, F. I., R. N. Wright, S. J. Fenves, and J. R. Harris, "Expressing Standards for Computer-aided Building Design," Computer Aided Design, Vol. 15, No. 6 (London: Butterworth and Co., 1983), pp. 329-334.

A summary of the SASE methodology and program.

[32] Rudnicki, R., "Decision Table Based Software for Designing with Standards," Unpublished M.S. Thesis (Pittsburgh: Carnegie-Mellon University, 1984).

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[33] Lopez, L. A., S. L. Elam and R. N. Wright, Mapping Principles for the Standards Interface for Computer Aided Design, NBSIR 85-3115 (Gaithersburg: National Bureau of Standards, 1985).

Defines the data interface requirements between SASE representations of standards and applications programs.

[34] Worthington, L. A., "An Interactive Program to Assist in the Compilation and Checking of Specification Provisions in Decision Table Format," Unpublished M.S. Thesis (Pittsburgh: Carnegie-Mellon University, 1985).

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[35] Slava, M. T., "Structure and Organization of Project Specifications," Unpublished M.S. Thesis (Pittsburgh: Carnegie-Mellon University, 1985).

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[36] Fenves, S. J., and J. H. Garrett, Jr., "Standards Representation and Processing," in Proceedings of IABSE Symposium on Steel in Buildings (Zurich: Int. Assoc. of Bridge and Str. Eng., 1985), pp. 107-114.

An Updated version of [29].

[37] Fenves, S. J., and J. H. Garrett, Jr., "Knowledge-Based Standards Processing," Int. Journal of Artificial Intelligence in Engineering, Vol. 1, No. 1 (London: Computational Mechanics Publications, April 1986), pp. 3-14.

A model of a knowledge-based system which uses the representational model of a specification to design structural components.

[38] Garrett, J. H., Jr. and S. J. Fenves, "A Knowledge-Based Standards Processor for Structural Component Design," Report R-86-157, Department of Civil Engineering (Pittsburgh: Carnegie-Mellon University, 1986).

A specification-independent knowledge-based system for the design of structural components. The designer inputs a hypothesis identifying the controlling behavior. The system translates the hypothesis into appropriate specification provisions, constructs the resulting constraints, and solves for the basic data by optimization or database lookup. The remaining applicable specification provisions are checked. If some of the provisions are violated, the system backtracks with a new hypothesis.

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[40] Fenves, S.J., M. T. Slava and J. P. Barnett, SASE - Standards Analysis, Synthesis, and Expression Program: User Manual, NBSIR 87-3514 (Gaithersburg: National Bureau of Standards, 1987).

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A detailed description of the SICAD (standards interface for computer aided design) programming environment developed as a support tool for research on the interface [33] between standards and computer aided design systems. The system supports automatic checking of a design for conformance with applicable provisions of a standard expressed in an augmented form of the SASE model.

NBS-114A (REV. 2-8C)

U.S. DEPT. OF COMM. BIBLIOGRAPHIC DATA SHEET (See instructions)	1. PUBLICATION OR REPORT NO. NBSIR 87-3513	2. Performing Organ. Report No.	3. Publication Date MAY 1987

4. TITLE AND SUBTITLE

Introduction to SASE: Standards Analysis, Synthesis, and Expression

5. AUTHOR(S)

Steven J. Fenves, Richard N. Wright, Fred I. Stahl and Kent A. Reed

6. PERFORMING ORGANIZATION (If joint or other than NBS, see instructions)

NATIONAL BUREAU OF STANDARDS
DEPARTMENT OF COMMERCE
WASHINGTON, D.C. 20234

7. Contract/Grant No.

8. Type of Report & Period Covered

9. SPONSORING ORGANIZATION NAME AND COMPLETE ADDRESS (Street, City, State, ZIP)

10. SUPPLEMENTARY NOTES

☐ Document describes a computer program; SF-185, FIPS Software Summary, is attached.

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The Standards Analysis, Synthesis, and Expression (SASE) methodology provides an objective and rigorous representation of the content and organization of a standard. Both the methodology and a computer program that implements it are described in this document in terms of two underlying conceptual models. The conceptual model for the information content of a standard is essentially independent of any particular organization and expression of the information. The fundamental unit of information in the model is a provision stipulating that a product of process have some quality. The highest level provisions in a standard are requirements that directly indicate compliance with some portion of the standard and are either satisfied or violated. Techniques are provided in SASE to ensure that individual provisions are unique, complete, and correct, and that the relations between provisions are connected, acyclic and consistent. Entities in SASE that represent the information content of a standard are data items, decision tables,

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☒ Order From National Technical Information Service (NTIS), Springfield, VA. 22161

14. NO. OF PRINTED PAGES

190

15. Price

$18.95

decision trees, functions, and information networks. The conceptual model for the organization of a standard is based on a logical classification system in which each requirement is classed in terms of its subject (product or process) and predicate (required quality). Techniques are provided in SASE for building and manipulating hierarchical trees of classifiers and testing the resulting organization for completeness and clarity. Entities in SASE that deal with the organization of a standard are classifiers, hierarchy, scopelist, index, organization, and outline. The SASE methodology is demonstrated in an analysis of a complete standard for concrete quality. An Annotated bibliography of the most significant relevant research reports is presented.